# Optimal grazing management systems for sheep and beef cattle in the hills and uplands

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# Executive Summary

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The uplands are complex systems supporting a variety of functions of environmental or social benefit. Within the UK, land with Less Favoured Area (LFA) status accounts for around 45% of the total agricultural area. The traditional basis of farming in the LFAs is the keeping of breeding sheep and suckler cows, and at the time this project began the uplands carried around 12 million breeding ewes and more than a million suckler cows, in each case just over 60% of the UK total. In the decades following the 2nd World War great efforts were made to improve agricultural productivity in the uplands. Large areas of land were ploughed and drained, and swards of cultivated grasses established. Improved permanent pasture and temporary grass leys today account for around one-third of the grazed areas of the hills and uplands in the UK. The two thirds of the land area which remain unimproved include some of the country's most spectacular and cherished landscapes. These areas are also the product of man's intervention, and while they contain habitats that are recognised as having international importance from a nature conservation perspective, there has been a decline in the extent and condition of many of these ecosystems as a result of inappropriate management. Incomes on hill and upland farms have been, and remain, heavily reliant on government support. The current study was set up in response to the uncertainty regarding the future of livestock systems within LFAs following reform of the CAP and the associated de-coupling of payments from production, and sought to quantify the economic and environmental impacts of different management scenarios. The specific objectives of the programme were: 1) to study the long-term effects of grazing *Molinia caerulea* dominant semi-natural rough grazing during the summer months by cattle or sheep on sward species composition, structure and nutritive quality, 2) to study the effects of differing cattle to sheep ratios when mixed grazing of improved permanent pastures in the uplands, 3) to study the production and environmental consequences of removing cattle from improved permanent pasture to graze semi-natural rough grazing during the summer months, and 4) to create a research platform for the study of upland systems. Experiment 1 was designed to meet Objective 1, and was a continuation of an experiment established in 2001 as part of LS3402. Experiment 2 was designed to fulfil Objectives 2 – 4. This systems experiment commenced in April 2004, with land and animal resources prepared for the introduction of livestock on treatments in spring 2005. Data collection ran for four years form 2005 – 2009.

Experiment 1 tested the hypothesis that summer grazing of *Molinia*-dominated grassland will lead to improved animal performance through changes in the short term in the structure of the vegetation, and in the long term through changes in both structure and species composition. The experiment was conducted on an area of undergrazed *Molinia*-dominant semi-natural rough grazing (SNRG) at ADAS Pwllpeiran. The study began in 2001 as part of LS3402, and was continued under the current programme. Three summer treatments were compared: 1) no grazing, 2) grazing by Welsh Mountain ewes and 3) grazing by yearling Welsh Black heifers. The cattle plots were grazed at a stocking density of 2 animals/ha i.e. equivalent to 0.30 LU/ha/annum, which was anticipated would achieve an utilisation rate of *Molinia* of 50 %. The sheep plots were stocked at a comparable level, equating to 8 ewes/ha. Analysis of data from regular vegetation surveys revealed grazing treatment had little impact on the botanical composition of the swards, but that there was significant change over the course of the experiment in the percentage sward cover of several of the main plant categories within the sward. While there was an increase in the percentage of *Molinia* within the sward over time the percentage accounted for by dwarf-shrubs decreased. Although grazing had comparatively little impact on the botanical composition of the sward, there were was an obvious increase in the proportion of green material within the grazed swards. It was anticipated that this would increase the nutritional value of the vegetation for stock, and young heifers were chosen as the experimental animals in order to be able to quantify the anticipated improvement in animal performance. While there was a significant effect of year on the liveweight gain of the cattle, the long-term pattern did not match that predicted. The growth rates of the heifers improved over the first three years of the experiment, but this performance was not sustained. These results highlight the importance of long-term data collection when assessing the impact of management regimes on semi-natural vegetation. Further research is required to explore alternative management options for such sites, such as rotational grazing across years.

Experiment 2 was conducted at the Bronydd Mawr Upland Research Centre. The total experimental area covered 43.25 ha improved pasture and 24 ha SNRG. A total of five treatments (systems), replicated twice, were implemented as follows: 1) sheep only grazing improved permanent pasture (PP) throughout the growing season (S PP), 2) sheep plus mainstream (Limousin) cattle at ratio of 6:1 grazing PP throughout the growing season (S/C6L PP), 3) sheep plus Limousin cattle at ratio of 6:1 with cattle removed to *Molinia caerulea*-dominated semi-natural rough grazing (SNRG) for 3 summer months (S/C6L SN), 4) sheep plus Limousin cattle at ratio of 12:1 with cattle removed to SNRG for 3 summer months (S/C12L SN), and 5) sheep plus rare breed (Belted Galloway) cattle at ratio of 6:1 with cattle removed to

SNRG for 3 summer months (S/C6BG SN). Treatment 5 formed the basis of the bolt-on project LS3408. Statistical analysis of data from LS3408 relied on comparisons with treatments from LS3407, and hence results from LS3408 are included in this report alongside those of LS3407. The sheep on all treatments were Beulah Speckled Face with Suffolk cross lambs. Improved pasture plots sizes included land allocation for sufficient silage to feed the stock grazing them through the winter months, and were designed to achieve an annual stocking rate of 1.6 LU/ha/annum. Grazing on the SNRG began in early June and ceased when utilisation of the current season's growth of *M. caerulea* reached 50 %. The experiment spanned a number of challenging years in terms of climatic conditions, and experienced the type of variation in rainfall pattern predicted to be a key feature of climate change in the uplands.

Regular vegetation sampling revealed that experimental treatment had little effect on the sward surface height, sward biomass or chemical composition of the improved pastures, although there was considerable variation in these parameters across the growing season. Chemical analysis of samples of material collected from the SNRG areas during the periods of summer grazing by cattle showed that the crude protein concentration of the *M. caerulea* on occasion equalled that of improved pasture. However, the water-soluble carbohydrate concentration of the *M. caerulea* was consistently low, with implications for nitrogen use efficiency. Year-to-year variation had a greater impact on sheep performance during the pre-weaning period of April to late July than did management system, but between-treatment differences in lamb liveweight gain led to lambs on the S PP system having a higher weaning weight than those on the S/C12L SN and S/C6BG SN systems. Management system had more impact on sheep performance during the post-weaning period from July to the end of September. At this time lamb liveweight gain was greatly influenced by treatment, with those on the S PP having the lowest growth rate, in keeping with results form previous mixed grazing experiments. The highest gains were recorded for those lambs included in systems where the cattle were removed to the SNRG. The Belted Galloway cows and their calves were smaller than their Limousin cross equivalents, which in turn strongly influenced the liveweight gains of the calves. The Limousin calves pastured with their dams on the *Molinia*-dominant rough grazing achieved liveweight gains in excess of 1 kg/d, and although these were significantly lower than the growth rates of those remaining on the PP, the weights of the Limousin calves on the different systems were broadly similar at the end of the summer grazing period. Type of pasture grazed during the summer period had no effect on the subsequently growth rate of the Limousin calves when pastured on the silage aftermath in the autumn. The figures for cow weight change over the summer period revealed a significant interaction between management system and year. Output in terms of lamb and calf liveweight gain per unit area of improved pasture were calculated, and combined to give the total output. The SPP system had the lowest overall output. The highest overall yield was recorded on the S/C6L SN system, with the S/C12L SN similar to that of the S/C6L PP. Further research is required to profile the chemical composition of native plant species in greater detail, and to investigate the extent to which nutrient use efficiency can be manipulated by altering the balance of different plant species within the diet. There is also a need to explore how environmental factors, including soil status and climatic conditions, influence the chemical composition of such plants, in order to better predict the nutritional value of vegetation at different sites. This information, together with corresponding vegetation survey data, would give a robust rationale for the development of grazing plans for specific sites that optimise the efficiency of use of nutrients available.

Regular butterfly and bird surveys were carried out to explore differences in the habitat value of the different pasture types. Preliminary data analysis suggested no significant effect of grazing system on bird density or species richness. Butterfly species richness was significantly higher in systems incorporating SNRG compared with improved pasture systems alone. This was because 93% of all butterflies recorded over the 4 years were observed in SNRG plots, reflecting the greater floristic diversity of these swards. Analysis of butterfly abundance and species richness on improved pasture alone (i.e. where data from SNRG plots was excluded) suggests significant differences between grazing systems. Systems where cattle were removed for 3 summer months appeared to have more butterfly species and in higher numbers. The SNRG areas also supported a greater diversity of bird species. However, the surveys also revealed that the improved pastures supported large numbers of birds, particularly invertebrate feeders, at specific times of the year. This suggests that diversity will be optimised when a mosaic of vegetation types are found within a locality.

The current project focussed upon the impact of incorporating cattle into upland systems on animal performance, and the associated effects on the structure, botanical composition and habitat value of the grazed sward. There is now an urgent need to expand this research to quantify the impact of different upland management scenarios on soil, water and air quality, and to identify ways of minimising the emissions of diffuse pollutants (particularly methane and other greenhouse gases) from associated livestock production sytems. This information is essential in order to identify and implement management options that deliver the biodiversity benefits of grazing on semi-natural vegetation communities while minimising the potentially negative environmental impact of upland livestock farming.

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
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   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

**INTRODUCTION**

The uplands are complex systems supporting a variety of functions of environmental or social benefit. Within the UK, land with Less Favoured Area (LFA) status accounts for around 45% of the total agricultural area. The traditional basis of farming in the LFAs is the keeping of breeding sheep and suckler cows, and at the time this project began the uplands carried around 12 million breeding ewes and more than a million suckler cows, in each case just over 60% of the UK total. In the decades following the 2nd World War great efforts were made to improve agricultural productivity in the uplands. Large areas of land were ploughed and drained, and swards of cultivated grasses established. Improved permanent pasture and temporary grass leys today account for around one-third of the grazed areas of the hills and uplands in the UK. Crucially, herbage production from these swards can be over five times higher than from indigenous grasslands, and consequently such pastures are vital to the viability of livestock farming in the hills. The two thirds of the land area which remain unimproved include some of the country's most spectacular and cherished landscapes. These areas are also the product of man's intervention, and while they contain habitats that are recognised as having international importance from a nature conservation perspective, there has been a decline in the extent and condition of many of these ecosystems as a result of inappropriate management. Incomes on hill and upland farms have been, and remain, heavily reliant on government support. Previous arrangements under the Common Agricultural Policy (CAP) were based on headage payments. This encouraged overstocking; in turn leading to overproduction of livestock, and overgrazing. The current study was set up in response to the uncertainty regarding the future of livestock systems within LFAs following reform of the CAP and the associated de-coupling of payments from production, and sought to quantify the economic and environmental impacts of different management scenarios.

Critical to the development and refinement of management guidelines for hill and upland areas is an improved understanding of plant/animal interactions within these grazed ecosystems. There is evidence from studies with both wild and domestic herbivores that different species of animal differ in their grazing habits. In general, the food requirements of mammals increase with increasing body weight as a result of increasing costs of maintenance and production, although crucially this increase is not linear. Consequently, a larger grazer requiring a greater absolute quantity of nutrients will have less time per unit of nutrient to spend selectively foraging than does a smaller grazer with a lower absolute requirement. As a result, cattle are generally less selective feeders than sheep, and would be expected to focus their grazing on taller, less digestible patches of vegetation in order to maximise their intake. Furthermore, they are more likely to be forced to move to more accessible parts of the sward once preferred areas have been grazed too short to allow intakes to be maintained, and experimental work has shown grazing by cattle to be beneficial in terms of controlling invasive hill species such as *Molinia caerulea*. Studies have shown that such differences in grazing behaviour can lead to opportunities for complementary pasture use. Previous experiments with sheep and cattle grazing have also shown that both mixed and sequential grazing systems deliver improved performance of one or both species, leading to a higher total output per unit area. These earlier studies indicated that sheep are in general more favoured by mixed grazing than cattle, and that in some cases improvements in lamb growth are achieved at the expense of cattle performance. This suggests that cattle are more susceptible than sheep to sward conditions, and are disadvantaged in situations where these two species become competitive. However, to date the bulk of this research has been conducted using growing cattle. The grazing behaviour of cows is known to be different to that of calves, with mature animals shown to be less selective grazers. Consequently opportunities for complementary grazing may be greater when sheep are mixed grazed with cows, provided intake levels can be maintained. Theoretically the ratio of cattle:sheep within a mixed grazing systems will also influence the degree of competition between these two species, with ratios of less than 1:6 believed to be necessary to deliver opportunities for complementary grazing. This has important implications as regards implementing mixed grazing systems on farm, as agricultural statistics reveal that there is considerable regional variation in the numbers of these two species, with the national average closer to 1:11.

The overall aim of this research programme was to design and test grazing management systems for sheep and beef cattle in the hills and uplands which meet environmental, market and economic objectives. The systems proposed were designed to: a) optimise stocking and husbandry of hill livestock to promote upland biodiversity, while making best use of the available resources, b) produce high quality, naturally reared animals that meet consumer demands using environmentally sustainable and welfare-friendly systems, c) utilise improved upland pastures in a cost-effective manner, and d) minimise diffuse pollution effects.

The specific objectives of the programme were:

1. To study the long-term effects of grazing *Molinia caerulea* dominant semi-natural rough grazing during the summer months by cattle or sheep on sward species composition, structure and nutritive quality.
2. To study the effects of differing cattle to sheep ratios when mixed grazing of improved permanent pastures in the uplands.
3. To study the production and environmental consequences of removing cattle from improved permanent pasture to graze semi-natural rough grazing during the summer months.
4. To create a research platform for the study of upland systems.

<u>Experiment 1</u> was designed to meet Objective 1, and was a continuation of an experiment established in 2001 on land at ADAS Pwllpeiran Research Centre as part of LS3402.

<u>Experiment 2</u> was designed to fulfil Objectives 2 – 4. This systems experiment commenced in April 2004, with land and animal resources prepared for the introduction of livestock on treatments in spring 2005. data collection ran for four years form 2005 – 2009.

## EXPERIMENT 1

This experiment tested the hypothesis that summer grazing of *Molinia*-dominated grassland will lead to improved animal performance through changes in the short term in the structure of the vegetation, and in the long term through changes in both structure and species composition.

### Materials and methods

The experiment was conducted on an area of undergrazed *Molinia*-dominant semi-natural rough grazing (SNRG) at ADAS Pwllpeiran, Ceredigion, Wales which had been not been grazed for approximately 10 years. The study began in 2001 as part of LS3402, and was continued under the current programme. Three summer treatments were compared: 1) no grazing, 2) grazing by Welsh Mountain ewes and 3) grazing by yearling Welsh Black heifers. There were two replicates of each treatment, with individual plots 2 ha in size. The cattle plots were grazed at a stocking density of 2 animals/ha i.e. equivalent to 0.30 Livestock Unit/ha/annum, which was anticipated would achieve an utilisation rate of *Molinia* of 50 %. This had been shown previously to be likely to lead to a reduction in the dominance of *Molinia*. The sheep plots were stocked at a comparable level, equating to 8 ewes/ha. The cattle used in each year were yearling Welsh Black heifers, and the sheep Welsh Mountain hoggs (2002) or dry Welsh Mountain ewes (all other years).

The summer grazing period began in June, with the exception of 2001 when movement restrictions resulting from the Foot and Mouth Disease outbreak resulted in the start being delayed until mid-July. The grazing generally ceased in mid September.

*Vegetation measurements*

Measurements of sward height and botanical composition were being taken regularly throughout the summer grazing period. On each occasion, the height, vegetation type and vegetation part of the first touch of a platform was recorded at 600 random sites across each plot. If the first touch was grass seed-head/stem another measure was taken of the underlying sward at the same place. To simplify presentation of the results, plants with similar functional and morphological characteristics have been grouped together. The category 'broad-leaved grasses' includes *Agrostis* spp, *Anthoxanthum odoratum* and *Holcus lanatus*, and 'fine leaved grasses' *Festuca* spp and *Deschampsia flexuosa*. 'Other monocots' refers to *Carex* spp., *Juncus* spp., *Luzula* spp., *Eriophorum angustifolium* and *Trichophorum cespitosum*, while 'dwarf shrubs' refers to *Calluna vulgaris*, *Erica* spp., *Empetrum nigrum* and *Vaccinium* spp.. The term 'other dicots' has been for *Potentilla erecta* and *Galium saxitile*. 'Moss' refers to both moss and lichens.

To monitor *M. caerulea* utilisation four exclosure areas (2 m x 2 m) were erected on each SNRG plot, with the exclosures moved to new sites at the start of each growing season. From turnout onto the SNRG the length of 120 ungrazed leaves within the enclosure areas of each plot was measured at three-weekly intervals, together with the length of 120 grazed leaves recorded along defined transects within each plot. For each measurement tillers were selected at random and all leaves on a tiller were measured. Utilisation was calculated for each plot as the difference in the mean length of ungrazed and grazed leaves, expressed as a percentage of the ungrazed length.

*Animal measurements*
The empty live weight and condition score of the cattle and sheep grazing the plots was recorded at the beginning and end of each grazing period.

*Invertebrate measurements*
During the fourth year of the experiment the impact of changes in sward structure and composition on invertebrate number and diversity was assessed using pitfall traps. Trapping stations were set up at five random sites across each replicate plot, with each station consisting of 5 traps sited 1 m apart. Traps were 80 mm in diameter, and were filled with ethylene glycol to a depth of 25 mm. A 25 mm square mesh was placed over each trap and secured with pegs. The contents of the traps were emptied after two consecutive four-week collection periods, corresponding with 14 to 41 days (Period 1) and 41 to 71 days (Period 2) respectively after grazing commenced.

*Data analysis*
The botanical composition data underwent an angular transformation prior to analysis. Following initial fitting and checking of distribution, General linear model analysis of variance (ANOVA) was carried out with Treatment and Year as factors, followed by repeated measures ANOVA with Greenhouse-Geisser epsilon to modify the degrees of freedom prior to calculating probability. Invertebrate data were analysed by regression using a generalised linear model with a Poisson distribution and a logarithmic link function.

**Results and Discussion**
While grazing treatment had little impact on botanical composition, there was significant change over the course of the experiment in the percentage sward cover of several of the main plant categories, as measured during the annual sward assessments in early June (prior to grazing commencing) (Table 1).

**Table 1**. Effect of management (sheep grazed, cattle grazed, ungrazed) and time on the percentage sward cover of the main plant categories within a previously undergrazed *M. caerulea*-dominated sward.

| Plant category | Management | Time | Management x Time |
|---|---|---|---|
| *Molinia* | * | *** | ns |
| Fine-leaved grasses | ns | * | ns |
| Broad-leaf grasses | ns | * | ns |
| *Nardus* | ns | ns | ns |
| Other monocots | ns | ns | ns |
| Dwarf shrub | ns | *** | ns |
| Other dicots | ns | ns | ns |
| Moss | ns | *** | ns |

While there was an increase in the percentage of *Molinia* within the sward over time (Fig 1), the percentage accounted for by dwarf-shrubs decreased (Fig. 2).

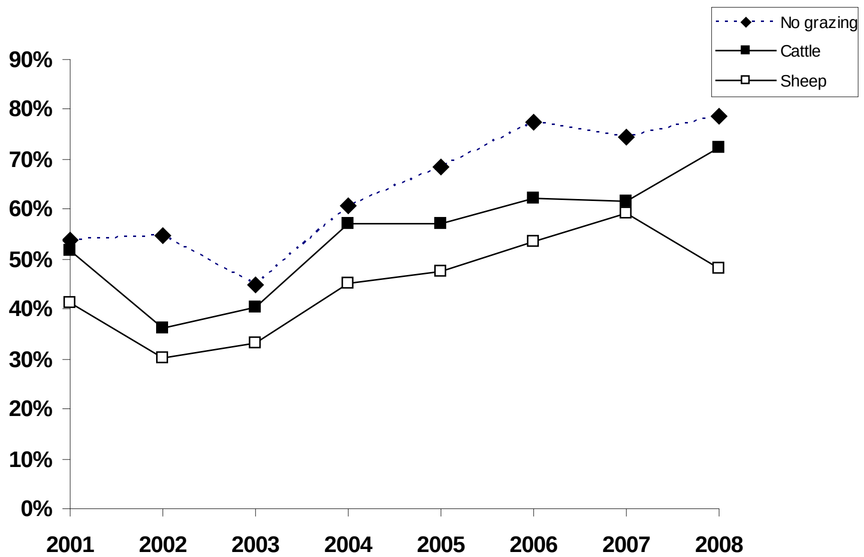



**Figure 1**. Percentage of sward cover accounted for by *Molinia caerulea* (annual measurements prior to grazing).

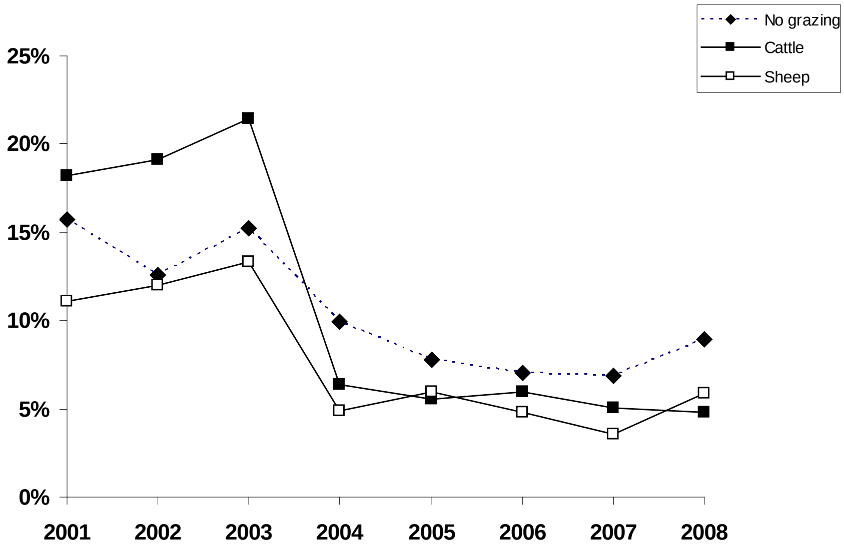



**Figure 2**. Percentage of sward cover accounted for by dwarf shrubs (annual measurements prior to grazing).

The lack of response to grazing in terms of botanical composition is likely to reflect limitations within the seed bank at the site. In comparison, the introduction of summer grazing by cattle on *Molinia*-dominant rough grazing at Bronydd Mawr had generated swards subsequently designated SSSI due to their floristic diversity, and it was observations made during that process this had led to Experiment 1 being initiated. Thus the findings highlight the variability of individual sites in terms of potential for change, and the need to take this into account when setting targets for management protocols.

Although grazing had comparatively little impact on the botanical composition of the sward, there were was an obvious increase in the proportion of green material within the grazed swards. It was anticipated that this together with a reduction in stemmy material would increase the nutritional value of the vegetation for stock, and young heifers were chosen as the experimental animals in order to be able to quantify the anticipated improvement in animal performance. While there was a significant effect of year on the liveweight gain of the cattle ($P$<0.001) (Fig 3), the long-term pattern did not match that predicted.

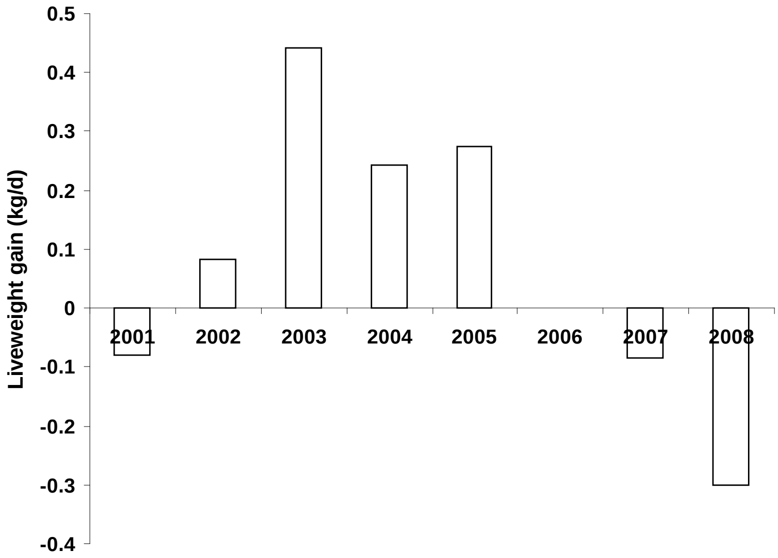



**Figure 3**. Performance of yearling Welsh Black heifers grazing *Molinia*-dominated rough grazing (data for 2006 is missing due to animals escaping during transit back from the plots).

The growth rates of the heifers improved over the first three years of the experiment (conducted under LS3402), but this performance was not sustained, and by 2007 and 2008 the animals were again losing weight. These results highlight the importance of long-term data collection when assessing the impact of management regimes on semi-natural vegetation. In comparison, growing stock grazing the *Molinia* rough grazing at Bronydd Mawr as part of previous experiments (LS1511) achieved acceptable liveweight gains in all years, exceeding 800 g/d at times. Likewise, the performance of suckler cows and calves was acceptable on the Bronydd Mawr pastures (Experiment 2, below). Again this highlights the potential variability in the impact of grazing at different sites, and the need for careful selection of stock types for particular situations. During the current experiment the performance of the sheep was also significantly affected by year ($P$<0.001), but their weight changes were always positive. Given the overall similarity in the impact of grazing by the heifers and sheep it would appear that sheep grazing may be a preferable option to growing cattle at sites such as that used in Experiment 1. Barren or dry cows may be a more appropriate cattle option given their lower relative requirements, but may be a less flexible option for farmers who do not currently keep cattle. In addition, mature cattle are less selective feeders than youngstock, and their impact on the vegetation may therefore be different. Further research is required to assess this objectively.

The reason for the decline in performance over time is not clear from the data that were collected. One possible explanation is that there was a reduction in sward biomass which influenced intake, and this has been suggested as a factor influencing growth rates when heifers of a similar age grazed *Nardus* grassland over several years (BD1228). Thus the results reinforce the need to explore alternative management options, such as rotational grazing, for certain types of SNRG.

Invertebrate sampling in 2004 revealed that in general the sward structural changes brought about by grazing reduced the numbers of invertebrates within the sward. During both sampling periods the numbers of ground beetles (*Carabidae* spp.) ($P$<0.001) and rove beetles (*Staphylinidae* spp) ($P$<0.01) were lower on the grazed plots than on the ungrazed plots. In contrast, the numbers of spiders (*Arachnid* spp.) were higher on the grazed plots in the first sampling period ($P$<0.05), and unaffected by treatment in the second. This illustrates the need for careful consideration when selecting indicator species. During the first sampling period grazing increased the number of froghoppers (*Homoptera* spp.) ($P$<0.01), but counts were lower on the grazed plots during the second period ($P$<0.001). In general the number of springtails (*Collembola* spp.) was also reduced by grazing. The results for the cattle and sheep grazed plots were generally similar, and the only consistent difference between these two treatments was in the number of froghoppers ($P$<0.01).

## EXPERIMENT 2

The project **LS3408** was a bolt-on treatment to the main systems experiment conducted as part of **LS3407,** relying on treatments within LS3407 as controls. Consequently, statistical analysis of the results has been conducted using data across all treatments, and results from LS3408 are included in this report alongside those of LS3407.

### Materials and method

*Experimental design*

The experiment was conducted at the Bronydd Mawr Upland Research Centre, Powys, and was sited at 310 to 360 m above sea level on Devonian sandstone of the Milford series. The total experimental area covered 43.25 ha improved pasture and 24 ha SNRG. A total of five treatments (systems), replicated twice, were implemented as follows: 1) sheep only grazing improved permanent pasture (PP) throughout the growing season (**S PP**), 2) sheep plus mainstream (Limousin) cattle at ratio of 6:1 grazing PP throughout the growing season (**S/C6L PP**), 3) sheep plus Limousin cattle at ratio of 6:1 with cattle removed to *Molinia caerulea*-dominated semi-natural rough grazing (SNRG) for 3 summer months (**S/C6L SN**), 4) sheep plus Limousin cattle at ratio of 12:1 with cattle removed to SNRG for 3 summer months (**S/C12L SN**), and 5) sheep plus rare breed (Belted Galloway) cattle at ratio of 6:1 with cattle removed to SNRG for 3 summer months (**S/C6BG SN**). Treatment 5 formed the basis of the bolt-on project **LS3408**.

Individual plot sizes on the PP were 2.25 ha for Treatment 1; 4.75 ha for treatment 2; 4.125 ha for Treatments 3 & 5; and 6.375 ha for Treatment 4. These plots sizes included land allocation for sufficient silage to feed the stock grazing them through the winter months (Table 2). Silage requirement estimates were based on results from earlier experiments.

**Table 2**. Summary of plot sizes and stocking rates.

| Treatment | Animal type and number | Total plot area (ha) | Annual stocking rate (LU/ha) | Silage area (ha) |
|---|---|---|---|---|
| 1 | 24 ewes | 2.25 | 1.6 | 0.5 |
| 2 | 24 ewes + 4 cows | 4.75 | 1.6 | 2.5 |
| 3 & 5 | 24 ewes + 4 cows | 4.125 | 1.6 | 2.5 |
| 4 | 48 ewes + 4 cows | 6.375 | 1.6 | 3.0 |

The same area of land within each plot was used for silage production each year, and is subsequently referred in the report to as grazed/ensiled (**Gr/En**) sward. The remaining portion of the plots was grazed only (**Gr**). In early spring, prior to turnout of the experimental animals, the plots were grazed by newly-lambed ewes. The number of ewes and lambs grazing was adjusted weekly to maintain an average sward height of around 4 cm, with plots balanced for number of ewes with twin and single lambs where possible.

The PP swards had been reseeded at least 15 years previously. Botanical separations at the start of the experiment revealed that at this time they were dominated by perennial ryegrass (45 %) with a white clover (*Trifolium repens*) content of less than 5 %. Unsown grasses were mainly meadow grasses (*Poa* spp.) (31 %) and bents (*Agrostis* spp.) (8 %), with smaller amounts of Yorkshire fog (*Holcus lanatus*) (3 %) and fescue (*Festuca* spp.) (1 %). Plot areas allocated to silage production were closed up at the beginning of May, with the crop harvested around mid June (weather permitting) when the estimated yield reaching 4.8 tonnes DM $ha^{-1}$. The crop was cut with a mower conditioner and baled after wilting for 24 - 48 hrs. All PP plots received fertiliser at a rate of 50 kg N $ha^{-1}$ in early spring when the soil temperature at a depth of 10 cm reached 5.5 °C. A second dressing of 80 kg N $ha^{-1}$, 32 kg $P_2O_5$ $ha^{-1}$ and 45 kg $K_2O$ $ha^{-1}$ was applied to the silage area at the time of close-up, and immediately following harvest these areas additional potash as necessary to maintain indices of 2.

Four of the six areas of *Molinia*-dominated vegetation grazed during the experiment had been entered into an agri-environment scheme (the Habitat Scheme) in 1996 as species-rich pastures. In addition, two of the fields had been designated Sites of Special Scientific Interest (SSSI) in 1985 due to their floristic diversity. Grazing on the SNRG began when there was sufficient biomass to sustain the cattle, and ceased when utilisation of the current season's growth of *M. caerulea* reached 50 %.

*Animals and management*
The sheep used on all treatments were Beulah Speckled Face ewes which were put to Suffolk rams. Experimental animals were selected from the main flock based on uniformity of live weight and body condition score, and stock allocation to plots was balanced for ewe live weight, litter size, lamb live weight and sex The plots were stocked to give a lamb to ewe ratio of 1.5:1, and an equal number of male and female lambs. Male lambs were castrated shortly after birth. Lambs were removed from the experiment when they weighed over 36 kg and had reached a body condition score equivalent to fat class 3L. In 2005 all finished lambs were sent for slaughter through a commercial abattoir. In 2006 – 2008 finished male lambs were again sent for slaughter, while finished female lambs were sold at market as breeding stock (as the price received was higher than for finished lambs). Any lambs remaining on the experimental plots at the end of September were removed from the experiment. The general health of all ewes on the plots was assessed in mid-August, with particular attention paid to the condition of the teeth and udder. Any with problems were classified as cast ewes, removed from the plots and replaced. The ewes were mated on the plots, with one ram turned out per plot, and rotated after 14 days. The rams were introduced in early October and remained with the ewes for a total of 6 weeks. The ewes were pregnancy scanned in early January.

The suckler cows used in Treatments 2 - 4 were Limousin crosses, and these were put in calf to a Limousin bull. Animals were allocated to treatments at the start of grazing according to age, live weight and condition score of the dam, and age, live weight and sex of the offspring. Male calves were castrated. The suckler cows used for Treatment 5 were Belted Galloways, in calf to a Belted Galloway bull. All calves were weaned around the end of September and removed from the experiment. Cows were mated in July following synchronisation using AI (both breeds in 2005, Limousin cross only 2006 – 2008) or natural service (Belted Galloways 2006 – 2008).

Animals were re-allocated to treatments at the beginning of each growing season. Any animal which had to be removed from the experiment was replaced by one of a similar type. Turnout of sheep began annually in April. Cattle grazing ran from turnout at the beginning of May until housing in early October. Following weaning in the third week of July, the lambs grazed the aftermaths as a priority. All cattle then grazed the aftermath with the lambs following the return of the cows on Treatments 3 – 5 from the SNRG. The silage area was opened up after any remaining lambs had been removed at the end of September. The Limousin-cross cows were housed from mid-October, with the date dependent on herbage availability and weather conditions. The Belted Galloway cows were removed from the plots at the same time, but wintered outdoors. During the winter the cows were fed grass silage (Limousin) or a mixture of grass silage and straw (Belted Galloway) to achieve a body condition score of 2.5 at the time of calving. The pastures were then grazed by sheep only until they were housed in early January.

Internal parasites were managed using a trigger drenching approach. Ewes received a fluke drench three weeks prior to mating. At this time faecal egg counts (FEC) were carried out to determine the need for anthelmintic drenching (FECPAK International Ltd, Dunedin, New Zealand). If a sufficiently high worm burden was detected then a drench of either a levamisole or ivermectin was administered. For the purpose of this experiment a high worm burden was considered to be any count in excess of 600 eggs per gram. A second fluke drench was administered 2-3 weeks after housing. A second FEC was undertaken at turnout to determine the need for anthelmintic treatment. If a high worm burden was idenitfied then a drench of either a levamisole or ivermectin was administered. Drenches were rotated on an annual basis between levamisoles, ivermectins and occasionally benzimidazoles to help prevent the build up of anthelmintic resistance within the flock. Lambs received a benzimidazole plus mineral (selenium and cobalt) drench at 5-7 weeks of age and again at 9-10 weeks of age. From approximately 12 weeks of age FECs were used to determine the need for drenching. Groups of lambs were monitored at three-week intervals pre-weaning and then fortnightly post-weaning. If a high worm burden was discovered then a drench of either a levamisole or ivermectin was administered, the use of these drenches again being rotated annually. Blowfly strike was prevented by applications of cyromazine.

*Vegetation measurements*
Sward height on the PP plots was measured weekly using an HFRO sward stick (50 measurements per plot). Herbage biomass was measured by cutting the herbage within a 14 cm x 144 cm quadrat to ground level using electric shears every 4 weeks. The number of cuts taken from each sub-plot was determined using the formula max(6,ceiling(5*area)), and ranged from 6 on the grazed/silage areas for Treatment 1, to 17 on the grazed only areas of Treatment 4. After cutting, the fresh weight of the material within each quadrat was recorded and two representative samples taken. The first was oven dried to determine dry matter (DM) content, and the second bulked on a plot basis. A sub-sample from this bulked material underwent botanical separation to determine sward composition. A second sub-sample of the bulked material from each plot was freeze-dried and milled prior to submission for chemical analysis.

At silage harvest the weights of all bales produced from each experimental plot was recorded. A representative sub-set of the bales from each plot were then sampled for chemical analysis, with the number per plot determined using the formula given for quadrat cuts above. The selected bales were cored and the cored material bulked to give a single sample per plot. Following freeze-drying and milling this was submitted for chemical analysis.

To monitor *M. caerulea* utilisation six exclosure areas (2 m x 2 m) were erected on each SNRG plot, with the exclosures moved to new sites at the start of each growing season. From turnout onto the SNRG the length of 120 ungrazed leaves within the enclosure areas of each plot was measured at fortnightly intervals, together with the length of 120 grazed leaves recorded along defined transects within each plot. For each measurement tillers were selected at random and all leaves on a tiller were measured. Utilisation was calculated for each plot as the difference in the mean length of ungrazed and grazed leaves, expressed as a percentage of the ungrazed length. Samples for subsequent analysis to determine sward chemical composition on the SNRG areas were collected every four weeks, to coincide with quadrat sampling on the improved pasture. A bulked sample was collected from across each plot by cutting vegetation within inter-tussock areas to ground level using mechanical shears. A separate bulked sample of current season’s growth of *M. caerulea* was collected from each plot at the same time.

*Animal measurements*
The body condition score (BCS) of the ewes and lambs was assessed by handling the loin using a scale from 1 to 5. The BCS of the cattle was determined in a similar way. The live weight and BCS of all stock was recorded at turnout and removal from plots. In addition, all animals were weighed and condition scored every three weeks during the pre-weaning period. Ewes and cattle were then weighed and scored every four weeks post-weaning, while the weaned lambs were weighed and condition scored every two weeks until they reached 36 kg, and then condition scored every week. The reproductive performance of ewes in the following year was estimated by ultrasonic scanning 85 – 100 d after the beginning of mating.

*Bird and butterfly monitoring*
Bird surveys were carried out weekly throughout the year using a modified version of the Common Bird Census. On each occasion the species and number of birds interacting with each experimental plot was recorded by an observer walking pre-defined transects. Butterfly surveys were carried out weekly where possible using a modified version of the United Kingdom Butterfly Monitoring Scheme. Data was collected from mid-April to mid-September on days which were calm, sunny and with a temperature of >12 °C. Surveyors walked a defined route across each plot and recording all butterflies seen within 5 m of the transect lines.

*Data analysis*
After initial exploration of the distribution of sward height data from the Gr and Gr/En plots, Lorenz curves were generated to assess uniformity and Gini and associated asymmetry coefficients calculated. Treatment effects on sward biomass, botanical composition and chemical composition at each sampling point were analysed by ANOVA with all pairwise comparisons tested using Student-Newman-Keuls. Repeated measures ANOVA and Residual Maximum Likelihood (REML) were used to explore changes in these parameters over the course of each growing season, and interactions with treatment. All animal performance assessments were made using plot as the experimental unit. Following initial data exploration using ANOVA with pre-defined contrasts, the data were re-analysed using REML. Data for each of the four years were analysed separately, before being combined using meta-analysis. Mixed-effects models were used to explore the effects of grazing system on bird and butterfly species richness and abundance.

## Results and Discussion

*Seasonal variation in management operations*

Meteorological data was collected at a weather station adjacent to the experimental plots. A comparison of data from each of the four years the experiment ran plus equivalent long-term means across the twenty-two years from 1986 to 2008 revealed that overall 2005 most closely resembled an 'average' season (data available as Table A1 in the Annex to this report). In 2006 a cold, wet spring was followed by higher than average summer temperatures. In contrast, 2007 experienced a mild spring followed by a relatively cool, wet mid-summer. The summer of 2008 also experienced higher than average rainfall. Indeed the rainfall was the most variable of all the meteorological parameters monitored, varying considerably between and within years (Fig 4).

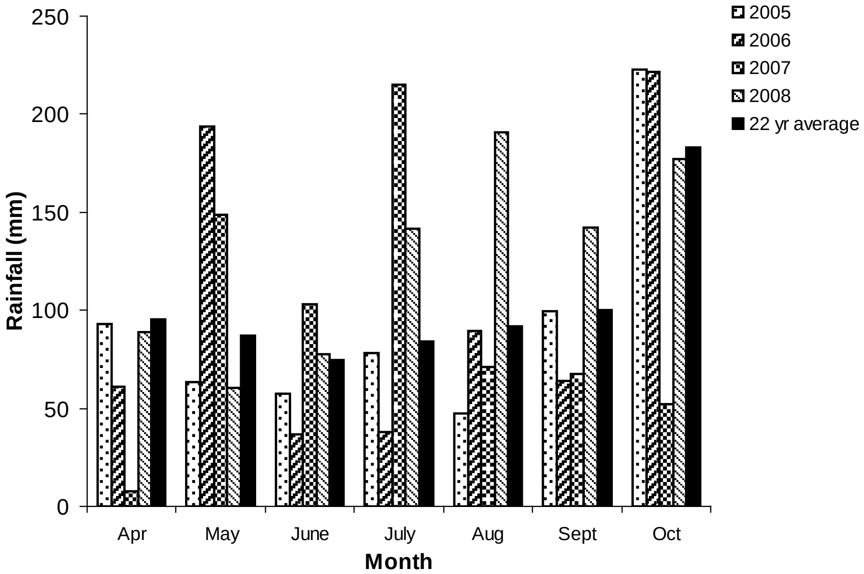



**Figure 4**. Average monthly rainfall across the growing season. Data is presented for each of the four years of the current study, together with the corresponding 22-year average from 1986 to 2008.

Weather inevitably influenced the timing of various management operations. In 2005 close-up on the grazed/ensiled areas was later than planned due to poor initial grass growth. Silage harvesting was subsequently disrupted by inclement weather, resulting in the cutting date for the second set of replicate plots being around a week later than that of the first set. This then had a knock-on effect in terms of delaying weaning of the lambs. In 2006 poor spring grass growth resulted in supplementary feeding being required on some plots. Concentrate feed (Ewbol Elite 18 Rolls; BOCM Pauls Ltd, Ipswich, UK) was supplied at a rate of 450 g/ewe/day until sward heights exceeded 3.5 cm, after which the supplementary feed was phased out over three days. This approach followed the protocol adopted in previous sheep system experiments. Cattle turnout was also delayed by inclement weather. Exceptionally dry conditions later in the summer also had an impact on grass growth, and cattle from one replicate of the S/C6L PP treatment had to be moved onto the silage aftermath early, when sward heights fell too low on the grazing only sward.

Higher than average temperatures led to uncharacteristically good grass growth in early spring of 2007, resulting in an initial turnout of 2 cows and calves per plot on 27 April. The remaining allocation per plot was turned out in early May in accordance with previous years. Due to seasonally poor weather conditions silage harvesting was delayed until July. The silage areas were closed up on 8 May with an anticipated cutting date of around the 11 June. However cutting did not begin until 9 July, and harvesting was not completed 8 August. This had a knock-on effect in terms of availability of aftermath grazing for lambs. In addition the cattle on S/C6L PP treatment had to be moved onto the aftermath areas before the lambs due to lack of grazing. While the weather conditions made it very difficult to keep to experimental protocol, the difficulties encountered reflected those experienced countrywide, as evidenced by the suspension of cross-compliance rules. There was an unusually cold spring in 2008 which delayed the initial fertilizer application to plots and turnout of sheep. The summer was then again very wet, but advantage was taken of a window in the weather and the silage was cut and harvested on time. The poor growing season did however result in the cattle being removed from the experiment over a month earlier than in previous years.

The experiment spanned a number of challenging years in terms of climatic conditions, and experienced the type of variation in rainfall pattern predicted to be a key feature of climate change, particularly in the uplands. Year to year variation was subsequently an important factor when analysing the data collected over the course of the project.

*Vegetation*

In the majority of previous experiments on improved pasture conducted at Bronydd Mawr sward heights were managed to a target surface sward height. These were normally those recommended as optimum for the type of stock grazing, and were maintained by put-and-take stock management. In the current experiment the plots were set-stocked, and consequently mean sward height and the associated variation about that mean could potentially vary between treatments, with implications for both animal performance and habitat value.

The mean sward surface heights on the Gr sub-plots across the growing season from the beginning of April to the end of September are given in Table 3, together with corresponding results for the Gr/En swards from the start of aftermath grazing until the end of September.

**Table 3.** Mean sward surface height of the grazed only plots from the beginning of April to the end of September, and of the Gr/En plots during aftermath grazing until the plots were opened up at the end of September. Values calculated using weekly averages, with associated ranges in parenthesis. (All values = cm)

| | 2005 | | 2006 | | 2007 | | 2008 | |
|---|---|---|---|---|---|---|---|---|
| *Gr sub-plots* | | | | | | | | |
| S PP | 5.7 | (3.7 - 9.2) | 5.1 | (2.9 - 7.8) | 5.5 | (3.7 - 8.7) | 5.7 | (3.3 - 8.4) |
| S/C6L PP | 7.0 | (4.4 - 9.8) | 6.0 | (3.4 - 10.8) | 7.2 | (4.0 - 11.6) | 5.5 | (3.4 - 9.3) |
| S/C6L SN | 5.9 | (3.9 - 8.2) | 5.3 | (3.5 - 9.9) | 5.5 | (3.7 - 10.2) | 4.9 | (3.3 - 7.9) |
| S/C12L SN | 5.5 | (3.9 - 7.8) | 4.5 | (3.3 - 8.0) | 5.0 | (3.8 - 7.8) | 4.6 | (3.2 - 6.8) |
| S/C6BG SN | 6.1 | (4.0 - 10.1) | 4.5 | (3.0 - 7.4) | 4.8 | (3.1 - 8.3) | 4.9 | (3.1 - 8.3) |
| *Gr/En subplot aftermath* | | | | | | | | |
| S PP | 8.9 | (3.7 - 13.6) | 5.2 | (3.5 - 8.6) | 6.6 | (5.1 - 8.8) | 7.7 | (3.7 - 13.4) |
| S/C6L PP | 12.7 | (9.5 - 17.9) | 8.0 | (5.4 - 10.5) | 5.9 | (4.1 - 7.2) | 6.7 | (4.1 - 11.5) |
| S/C6L SN | 11.0 | (7.0 - 16.4) | 8.4 | (5.3 - 10.6) | 6.7 | (4.9 - 8.5) | 8.3 | (4.4 - 13.8) |
| S/C12L SN | 10.6 | (6.0 - 16.5) | 7.6 | (5.7 - 9.9) | 6.5 | (4.7 - 10.0) | 9.2 | (4.8 - 15.2) |
| S/C6BG SN | 11.9 | (9.1 - 16.3) | 9.7 | (7.6 - 12.1) | 8.6 | (5.9 - 11.1) | 9.3 | (5.9 - 13.1) |

Studies have indicated that sward surface heights of 4 – 5 cm and 8 – 10 cm provide near maximum intakes of herbage for sheep and cattle respectively, and earlier experimental work with mixed grazing of sheep with beef steers sought to maintain a target sward height of 6 cm. The average swards heights on the Gr swards were in keeping with such aspirations, although set-stocking management meant that these varied across the course of the growing season, as reflected in the ranges. The lowest values were generally recorded at the start of the growing season, prior to cattle turnout in May or during periods of exceptionally dry weather. Not surprisingly the range of values recorded on the Gr/En swards during aftermath grazing was greater. With initial turnout heights at 12 cm plus, the intake rate of the lambs could have been compromised. In those systems which incorporated co-grazing with cattle, removal of mass by the cattle could have improved sward accessibility for the lambs.

The degree of variation in sward surface height brought about through grazing could have implications for e.g. invertebrate populations, and so the variation in height across the growing season and within plots of different treatments was explored. This was done using the 50 measurements per plot made on a weekly basis. Separate analyses were carried out for the Gr and Gr/En swards. No clear pattern in terms of differences in the distribution of the fitted means and associated coefficients of variation for the different treatments were found. Lorenz curves were plotted to explore the variation further, and the associated Gini coefficients are summarised in Table 4 (the Gini coefficient is a measurement of statistical dispersion, with a higher value indicating the data were more uneven distributed).

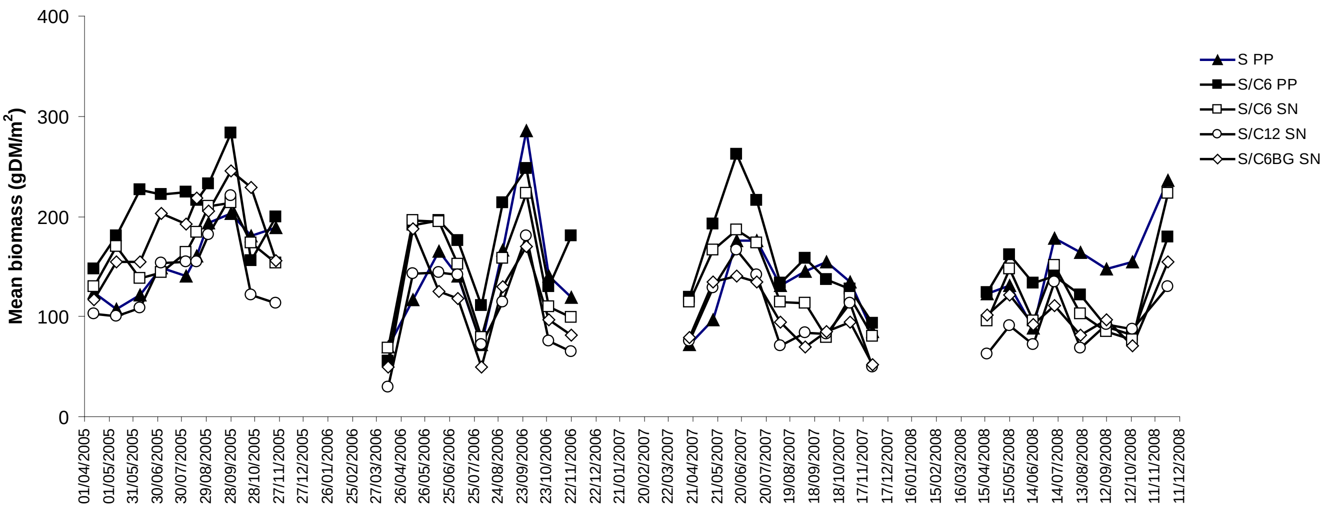
**Table 4**. Gini coefficients associated with surface heights measurements on swards of each treatment. Separate calculations were carried out for swards which were grazed only (Gr) and those which were grazed and ensiled (Gr/En)

| | S PP | S/C6 PP | S/C6 SN | S/C12 SN | S/C6BG SN | s.e.d. | Prob. |
|---|---|---|---|---|---|---|---|
| Grazed only | | | | | | | |
| 2005 | 0.127 | 0.114 | 0.119 | 0.109 | 0.108 | 0.0092 | ns |
| 2006 | 0.104 | 0.135 | 0.129 | 0.114 | 0.113 | 0.0257 | ns |
| 2007 | 0.091 | 0.161 | 0.146 | 0.117 | 0.131 | 0.0018 | ns |
| 2008 | 0.126 | 0.138 | 0.111 | 0.110 | 0.117 | 0.0115 | ns |
| Grazed/ensiled | | | | | | | |
| 2005 | 0.185 | 0.221 | 0.204 | 0.181 | 0.195 | 0.0291 | ns |
| 2006 | 0.142 | 0.147 | 0.170 | 0.154 | 0.170 | 0.0169 | ns |
| 2007 | 0.118 | 0.103 | 0.150 | 0.138 | 0.138 | 0.0155 | ns |
| 2008 | 0.181 | 0.110 | 0.162 | 0.189 | 0.164 | 0.0164 | * |

Treatment was found to have no effect on the Gini coefficients calculated for the Gr swards. Thus the inclusion of cattle grazing, whether for just part or all of the growing season, did not alter the evenness of the sward surface height. With the exception of 2008, management system also had no effect on the coefficients calculated for the Gr/En swards. In general, the coefficients of the Gr/En swards were higher than the equivalent values for the Gr swards.

The biomass of the Gr and Gr/En swards across each of the four years the experiment ran is depicted in Fig. 5. Not surprisingly the swards managed as a silage crop followed by aftermath grazing underwent greater change in biomass over the course of each growing season compared to those grazed throughout (note differences in scale on graphs). The greatest yield of all was recorded in 2007, and corresponds to the exceptionally long close-up period caused by wet weather delaying harvest. Type of management system did not significantly influence the herbage biomass of the Gr swards at any stage, and at only two time points (9/6/2005, 27/7/2006) were there significant treatment differences (*P*<0.05) in the biomass of the Gr/En swards. The coefficients of variation associated with the mean values for herbage biomass were variable and comparatively high, reaching up to 80 %. However, the pattern of variation within a season tended to be similar regardless of whether the swards were grazed only or grazed and ensiled, and analysis of variance revealed that again management system had very little influence on the results obtained.

a)




b)

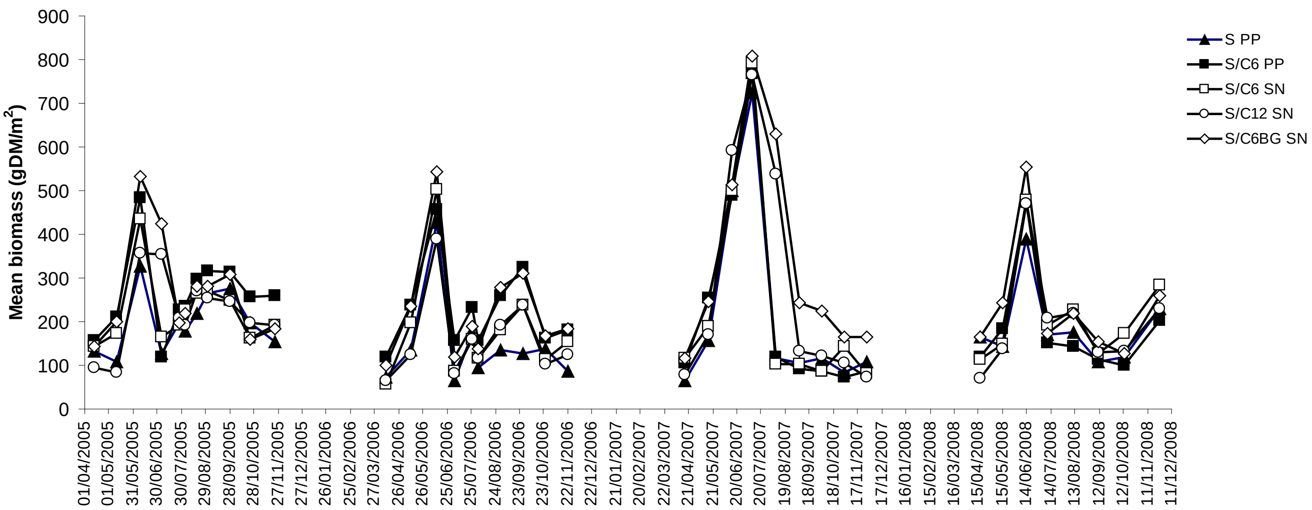
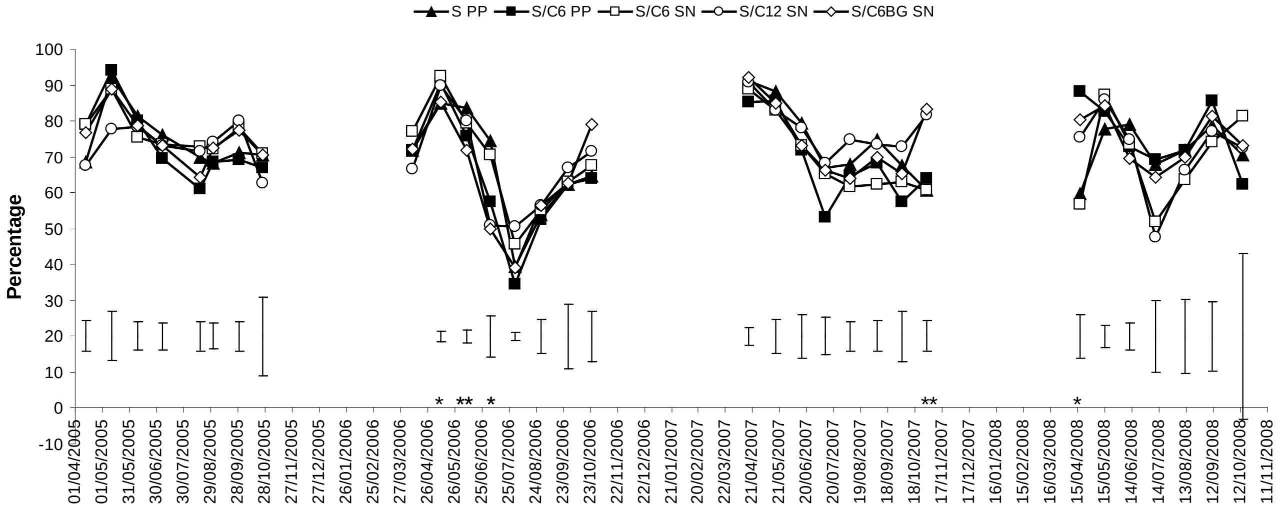



**Figure 5**. Effect of management system on herbage biomass within plots a) grazed only throughout the growing season and b) grazed, closed up for silage production and grazed again as aftermath.

Botanical separations of subsamples of the herbage cut from the Gr plots revealed that sward composition was also largely unaffected by management system (Fig. 6), but that again there were predictable changes during the course of the growing season.

a)

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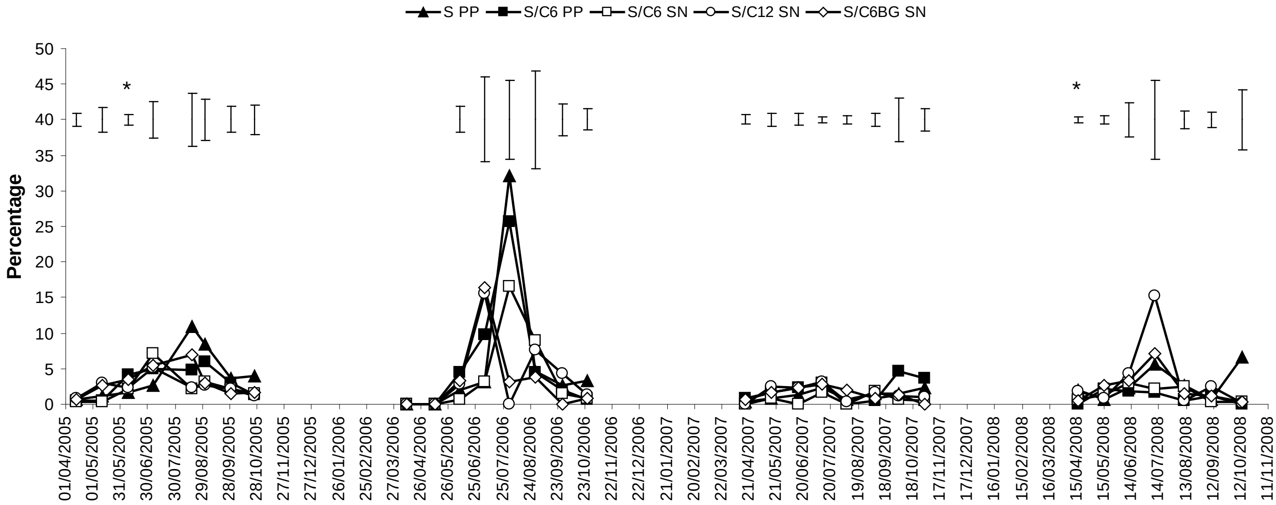


c)

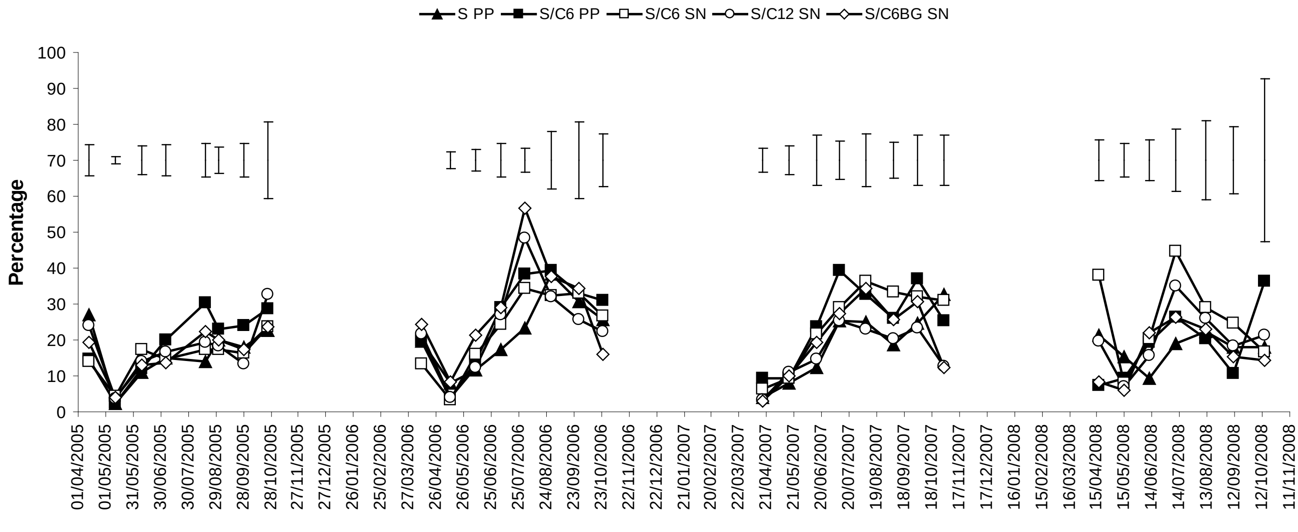


**Figure 6**. Effect of management system on percentages of a) live grass leaf, b) grass stem and c) dead material within swards of improved permanent pasture grazed from April to December. Results are presented for botanical separations carried out on vegetation collected at monthly intervals from April to October. In November and December there was insufficient material for separation, and in April of 2006 low biomass on some plots and associated missing values meant statistical analysis was not possible.

The categories of white clover and unsown dicots generally accounted for 5 % or less of the sward (not shown), and there were no effects of treatment recorded for either category. Live grass leaf was generally the main component within the sward. However, the dry summer of 2006 was associated with a marked reduction in the percentage of green leaf and corresponding increased in grass stem and dead material. While it was anticipated that this might be linked to reductions in CP and WSC concentrations and digestibility, the averages across the season were in keeping with those for other years (Table 5). System of management also had little impact on the chemical composition of the grazed swards.

**Table 5.** Effect of system on the chemical composition of the Gr swards across the growing season from April to September (all values g/kg DM).

| Year | | S PP | S/C6L PP | S/C6L SN | S/C12L SN | S/C6BG SN | s.e.d. | Prob. |
|---|---|---|---|---|---|---|---|---|
| 2005 | CP | 155 | 146 | 159 | 177 | 166 | 6.9 | *** |
| | WSC | 102 | 112 | 101 | 108 | 111 | 11.9 | ns |
| | NDF | 416 | 437 | 413 | 433 | 434 | 23.7 | ns |
| | DOMD | 545 | 553 | 551 | 572 | 557 | 19.1 | ns |
| 2006 | CP | 147 | 146 | 153 | 159 | 165 | 9.8 | ns |
| | WSC | 105 | 110 | 96 | 98 | 104 | 8.8 | ns |
| | NDF | 431 | 449 | 444 | 430 | 442 | 23.1 | ns |
| | DOMD | 540 | 550 | 535 | 550 | 548 | 17.6 | ns |
| 2007 | CP | 153 | 142 | 146 | 160 | 147 | 14.7 | ns |
| | WSC | 100 | 112 | 104 | 114 | 131 | 8.4 | ** |
| | NDF | 502 | 495 | 477 | 486 | 503 | 18.8 | ns |
| | DOMD | 569 | 555 | 562 | 577 | 587 | 22.0 | ns |
| 2008 | CP | 159 | 146 | 153 | 167 | 170 | 10.1 | ns |
| | WSC | 101 | 119 | 105 | 109 | 109 | 12.6 | ns |
| | NDF | 428 | 458 | 433 | 399 | 424 | 22.9 | ns |
| | DOMD | 567 | 575 | 562 | 571 | 580 | 19.7 | ns |

Where CP = crude protein, WSC = water-soluble carbohydrates, NDF = neutral-detergent fibre, DOMD = digestible organic matter in the dry matter.

The results from earlier studies suggested the reported production benefits from mixed grazing of cattle and sheep may arise in part from different preferences as regards plant species and parts. Thus the less selective grazing habits of cattle could lead to a reduction in the dead and stemmy material avoided by sheep, and/or an increase in the proportion of white clover, with both scenarios potentially leading to an improvement in sward nutritional value. Such studies were generally conducted at very low ratios of cattle:sheep; often 1:1. The current study was conducted at ratios more in keeping with those likely to be found in practice, and at these ratios there was no evidence of a shift in either sward botanical or chemical composition.

The high rainfall in 2007 and the associated lateness of the silage harvests meant that the overall yield that year was substantially higher than in other years (Table 6). However, there was little evidence that the greater maturity of the crop had influenced the corresponding chemical composition values.

**Table 6.** Total silage yield per annum in terms of fresh matter, together with the chemical composition the swards at the time of harvest (all values g/kg DM, except yield (kg FM/ha) and DM (g/kg FM).

| | | Chemical composition | | | | |
|---|---|---|---|---|---|---|
| | Fresh matter yield | DM | CP | WSC | NDF | DOMD |
| 2005 | 19863 | 197 | 175 | 119 | 453 | 640 |
| 2006 | 16306 | 341 | 120 | 116 | 550 | 557 |
| 2007 | 25569 | 158 | 134 | 108 | 536 | 584 |
| 2008 | 13958 | 161 | 143 | 127 | 554 | 580 |

Analysis of samples of material collected from the SNRG areas during the periods of summer grazing by cattle revealed the DM content of the *M. caerulea* was higher than that of the inter-tussock grasses, and both generally had a higher DM content than the improved permanent pasture (Table 7). With the exception of the first season, the CP concentration of the inter-tussock areas was substantially lower than that of the *M. caerulea,* which on occasion equalled that of PP. However, the WSC concentration of the *M. caerulea* was consistently low, with implications for nitrogen use efficiency. Not surprisingly the NDF concentrations of the native grasses were consistently higher than those of the PP, and this in turn influenced the digestibility values obtained.

**Table 7**. Mean chemical composition of current season's growth of *M. caerulea* and intertussock areas within *Molinia*-dominated SNRG at the time of cattle grazing, together with equivalent values for swards of the S/C6L PP systems (all values g/kg DM, except DM (g/kg FM).

| | | DM | CP | WSC | NDF | DOMD |
|---|---|---|---|---|---|---|
| 2005 | *M. caerulea* | 371 | 126 | 69 | 675 | 699 |
| | Inter-tussock | 315 | 119 | 82 | 592 | 677 |
| | PP | 239 | 127 | 125 | 485 | 561 |
| 2006 | *M. caerulea* | 373 | 116 | 50 | 695 | 460 |
| | Inter-tussock | 337 | 90 | 80 | 625 | 463 |
| | PP | 295 | 130 | 132 | 486 | 563 |
| 2007 | *M. caerulea* | 391 | 120 | 56 | 717 | 482 |
| | Inter-tussock | 336 | 98 | 82 | 632 | 493 |
| | PP | 235 | 120 | 134 | 500 | 547 |
| 2008 | *M. caerulea* | 330 | 124 | 50 | 722 | 493 |
| | Inter-tussock | 258 | 97 | 73 | 646 | 501 |
| | PP | 184 | 141 | 116 | 488 | 577 |

*Animal performance*

A breakdown of the effects of management system on the performance of the lambs and ewes in each of four years the experiment ran is given in Tables A2 and A3 in the accompanying Annex. Lamb growth rates were generally higher pre weaning compared to post weaning (Figure 7).

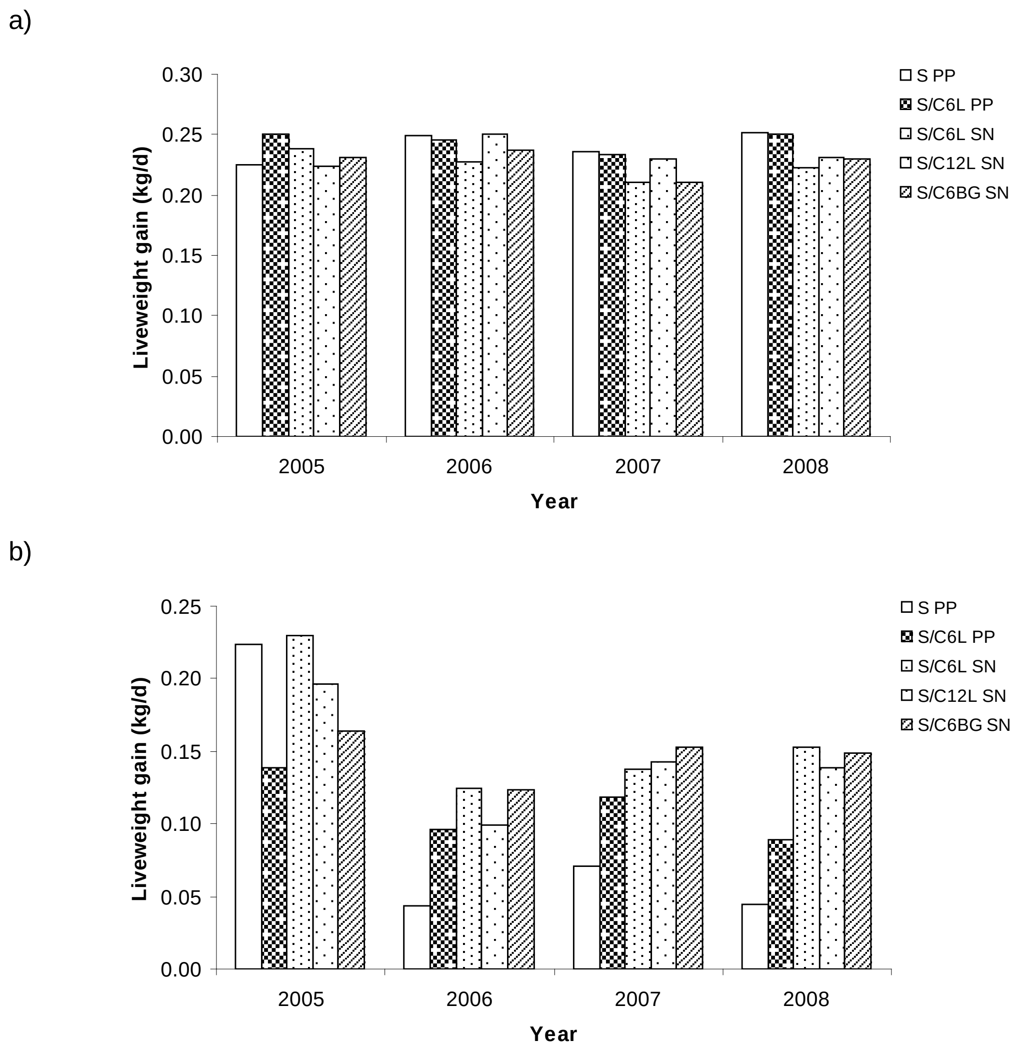


**Figure 7**: Lamb liveweight gain during a) pre-weaning from April to late July/early August, and b) post-weaning from late July/early August to end of September.

While performance pre weaning was comparatively consistent, there was a change in the post-weaning growth rates over time. The pattern of liveweight gain on the different treatments in 2005 was different to that in later years, but by the second year of grazing under the experimental regimes there was a consistent pattern of improved liveweight gains for the lambs mixed grazed with cattle compared to those on the sheep only system. However, although the differences in mean growth rates on the different treatments were often substantial, comparatively few were statistically significant as a result of increased within-plot variation in growth rates post weaning period.

The results from the different years were subsequently combined in a meta-analysis in order to more clearly define the effect of the treatments imposed. Overall, Year had a greater impact on sheep performance during the pre-weaning period of April to late July than did management system (Table 8). However, between-treatment differences in lamb liveweight gain led to lambs on the S PP system having a higher weaning weight than those on the S/C12L SN and S/C6BG SN systems. A significant effect on ewe BCS was also noted, but the differences in score were comparatively small. There was no effect of treatment on ewe weight change during lactation. Management system had more impact on sheep performance during the post-weaning period from July to the end of September. At this time lamb liveweight gain was greatly influenced by treatment, with those on the S PP having the lowest growth rate, in keeping with results form previous mixed grazing experiments. The highest gains were recorded for those lambs included in systems where the cattle were removed to the SNRG. The final live weights of the lambs followed the patterns of growth rates during this period, with heavier lambs produced from the systems incorporating intermittent grazing by cattle. However, some of these lambs also took slightly longer to finish. Ewe performance was largely unaffected by grazing system during this period. Although treatment influenced ewe weight change during the autumn/winter period from the end of September through to early January, the BCS of the ewes at the time of removal from the plots was similar on all treatments.

**Table 8.** Effect of management system on performance of ewes and lambs from turnout in April to weaning in July (pre-weaning), from weaning to removal of unfinished lambs in late September (post-weaning), and from end of September to removal of ewes for housing in early January (autumn). Analysis carried out on data collected 2005 – 2008.

| | S PP | S/C6L PP | S/C6L SN | S/C12L SN | S/C6BG SN | s.e.d. | S | Y | S x Y |
|---|---|---|---|---|---|---|---|---|---|
| *Pre-weaning* | | | | | | | | | |
| Initial ewe BCS | 2.43 | 2.38 | 2.40 | 2.41 | 2.60 | 0.132 | ns | *** | ns |
| Initial lamb weight (kg) | 10.8 | 10.8 | 10.6 | 10.7 | 10.6 | 0.27 | ns | *** | ns |
| Lamb weight at weaning (kg) | 35.9 | 35.3 | 34.3 | 34.0 | 33.8 | 1.53 | * | *** | ns |
| Lamb liveweight gain ($g\ d^{-1}$) | 241 | 245 | 225 | 234 | 227 | 18.4 | ** | * | ns |
| Ewe liveweight change ($g\ d^{-1}$) | 75 | 60 | 53 | 65 | 54 | 21.4 | ns | *** | ns |
| Ewe BCS change | 0.003 | 0.003 | 0.002 | 0.003 | 0.001 | 0.0011 | ** | * | ns |
| *Post-weaning* | | | | | | | | | |
| Ewe live-weight change ($g\ d^{-1}$) | 73 | 71 | 71 | 89 | 82 | 21.3 | ns | *** | ns |
| Ewe BCS change | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.0003 | * | * | ns |
| Lamb liveweight gain ($g\ d^{-1}$) | 91 | 101 | 144 | 130 | 132 | 29.1 | *** | ** | ns |
| Lamb final weight (kg) | 38.9 | 39.1 | 39.9 | 39.5 | 39.5 | 0.47 | *** | *** | ns |
| Days to finish | 116 | 120 | 128 | 121 | 126 | 5.71 | ** | ** | ns |
| *Autumn/winter* | | | | | | | | | |
| Ewe liveweight change ($g\ d^{-1}$) | 23 | 47 | 38 | 22 | 52 | 16.0 | *** | *** | ns |
| Final ewe BCS | 3.09 | 3.09 | 3.01 | 3.11 | 3.12 | 0.076 | ns | * | ns |

Where S = management system, Y = year

The Belted Galloway cows and their calves were smaller than their Limousin cross equivalents, in keeping with what would be expected of a native breed type. This had an impact on the associated liveweight gains of the calves, with growth rates of the Belted Galloway calves on average at least 300 g/d less than that of the Limousin calves, regardless of pasture type or stage of growing season (summer or autumn grazing). The results from each of the experimental years are summarised in Tables A4 and A5 of the Annex. Plotting of the calf liveweight gains from the summer grazing period in each of the four years revealed that the pattern of treatment differences was combatively consistent across the experiment (Figure 8), despite the year-to-year variation in climate and associated growing conditions.

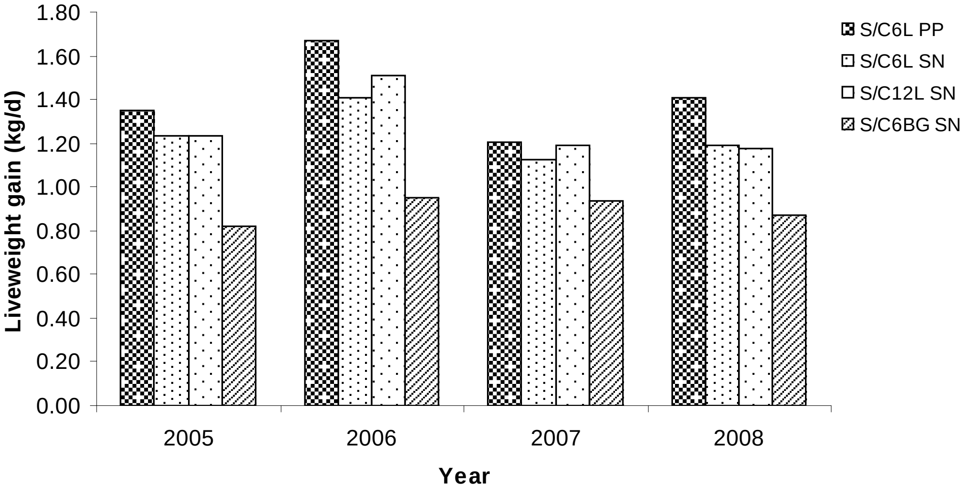


**Figure 8**: Calf liveweight gain during the summer grazing period of early May to late August/early Sept, when cattle were removed to graze the SNRG.

Analysis across the four years revealed that the Limousin calves pastured with their dams on the *Molinia*-dominant rough grazing had achieved average liveweight gains in excess of 1 kg/d, and although these were significantly lower than the growth rates of those remaining on the PP, the weights of the Limousin calves on the different systems were broadly similar at the end of the summer grazing period (Table 9). Type of pasture grazed during this period had no effect on the subsequently growth rate of the Limousin calves when pastured on the silage aftermath in the autumn. The figures for cow weight change over the summer period revealed a significant interaction between management system and year. The Limousin cows grazing the SNRG lost weight in both 2006 and 2007, but gained weight in the other two years. In comparison the Belted Galloway cows gained weight in every year; achieving over 650 g/d in 2008. Despite the weight loss of the Limousins, their BSCs were not unduly affected, and the scores recorded at the end of September were similar to those at turnout.

**Table 9.** Effect of management system on performance of cows and calves from the time of turnout onto semi-natural rough grazing (SN) in early June to return to permanent pasture (PP) (summer), and from return to PP until removal for weaning and housing at the beginning of October (autumn). Analysis carried out on data collected 2005 – 2007.

| | S/C6L PP | S/C6L SN | S/C12L SN | S/C6BG SN | s.e.d. | S | Y | S x Y |
|---|---|---|---|---|---|---|---|---|
| *Summer* | | | | | | | | |
| Calf initial weight (kg) | 109 | 114 | 114 | 77 | 2.9 | *** | ** | * |
| Calf liveweight gain (kg $d^{-1}$) | 1.326 | 1.170 | 1.196 | 0.848 | 0.0838 | *** | ns | ns |
| Calf final weight (kg) | 207 | 201 | 203 | 141 | 4.1 | *** | * | * |
| | | | | | | | | |
| Cow initial weight (kg) | 622 | 624 | 627 | 513 | 13.6 | *** | *** | ns |
| Cow initial BCS | 2.62 | 2.65 | 2.58 | 2.76 | 0.061 | * | ns | ns |
| Cow weight change (kg $d^{-1}$) | 0.256 | -0.225 | 0.016 | 0.300 | 0.1204 | *** | *** | * |
| Cow final weight (kg) | 641 | 605 | 627 | 540 | 13.1 | *** | * | ns |
| Cow final BSC | 2.63 | 2.56 | 2.58 | 2.85 | 0.056 | *** | ns | ns |
| | | | | | | | | |
| *Autumn* | | | | | | | | |
| Calf liveweight gain (kg $d^{-1}$) | 1.516 | 1.373 | 1.331 | 1.004 | 0.2267 | *** | * | ns |
| Calf final weight (kg) | 258 | 252 | 252 | 173 | 5.3 | *** | *** | * |
| | | | | | | | | |
| Cow liveweight gain (kg $d^{-1}$) | 0.489 | 0.441 | 0.185 | 0.481 | 0.217 | ** | ** | ns |
| Cow final weight (kg) | 656 | 627 | 638 | 558 | 11.9 | *** | * | ns |
| Cow final BCS | 2.68 | 2.58 | 2.61 | 2.90 | 0.073 | ** | * | ns |

Using the liveweight gain values from the meta-analysis output in terms of lamb and calf liveweight gain per unit area of improved pasture were calculated, and combined to give the total output (Table 10). Given that all lambs and calves were removed from the systems by the beginning of October, this equates to the annual production figures. The calculations were made using the entire PP plot areas, and therefore are all based on an annual stocking rate of 1.6 LU/ha/annum. Both Year and System had highly significant effects on the results obtained. Not surprisingly SPP had the highest yield of lamb, but with no calf yield this had the lowest overall output. The highest overall yield was recorded on the S/C6L SN system, with the S/C12L SN similar to that of the S/C6L PP.

**Table 10.** Effect of management system on total liveweight of lambs and calves gained across the growing season from April to early October. All values kg/ha PP.

| | S PP | S/C6L PP | S/C6L SN | S/C12L SN | S/C6BG SN | s.e.d. | S | Y | S x Y |
|---|---|---|---|---|---|---|---|---|---|
| Total calf output | 0.0 | 125 | 133 | 86 | 97 | 3.9 | *** | *** | * |
| Total lamb output | 142 | 71 | 83 | 106 | 84 | 2.3 | *** | ** | ns |
| Total system output | 142 | 196 | 216 | 192 | 181 | 4.9 | *** | *** | ns |

Corresponding sales income across the four years for the four treatments based on sheep with and without Limousin cattle were calculated, and these are summarised In Table A6 and Figures A1 and A2 in the Annex. The figures were calculated using sales values for the lambs and calves. These were unavoidably influenced by market values within the locality, but nevertheless some interesting trends emerged.

There were significant effects of both management system ($P$<0.01) and year ($P$<0.001) on the proportion of lambs reaching the weight and condition score criteria for slaughter within the main growing season, with the S PP treatment having the highest proportion of lambs remaining on the plots at the end of September. Given that the average price for finished lambs was substantially higher than that of store lambs this represents a comparative loss in sales value. In 2005 all the finished lambs were sent for slaughter through a commercial abattoir, and the corresponding results are given in Table A6. Management system was found to have had no effect on carcass weight, killing out percentage or sales value. Difficulties in getting the upland lambs produced from the experiment to meet supermarket scheme specifications led to a change in finished lamb destination from 2006 – 2008, with a switch to selling the majority of the animals live through local markets. Regardless of destination (abattoir/market), the average price achieved per head per plot for finished lambs remained unaffected by management system, although it did vary between years, with the highest value recorded in 2008. There was also a steady rise year-on-year in the price achieved for the calves, which were sold at market just after weaning in early October. In contrast to the lamb results, management system had an effect on the price per head achieved for the calves. When the lamb and calf sales were combined and expressed per unit area management system was also found to have had a significant effect on overall income ($P$<0.001), with the highest value (£716/ha) recorded on the S/C6L SN treatment.

*Birds and butterflies*

While several recent studies have addressed concern regarding the widespread decline of farmland birds in arable landscapes, there is comparatively little information available regarding the effect of upland sward management on bird populations. In the past, 'improvement' of upland pastures to provide higher forage yields and better grazing resulted in large areas being drained, ploughed and re-seeded with limited ranges of competitive grasses. In comparison SNRG pastures are generally more structurally and botanically diverse. Such differences in sward characteristics will affect the potential energetic gain and predation risks associated with a patch, and are likely to influence habitat selection.

Most bird species were not recorded in sufficient numbers to permit statistical analysis at the species level. Species were therefore assigned to functional groups, based on ecological and taxonomic characteristics. The group granivorous passerines included chaffinch (*Fringilla coelebs*), linnet (*Carduelis cannabina*), goldfinch (*C. carduelis*), bullfinch (*Pyrrhula pyrrhula*), redpoll (*C. flammea*) and reed bunting (*Emberiza schoeniclus*). Invertebrate feeders recorded were blackbird (*Turdus merula*), fieldfare (*T. pilari*), mistle thrush (*T. viscivorous*), redwing (*T. iliacus*), song thrush (*T. philomelos*), blackcap (*Sylvia atricapilla*), grey wagtail (*Motacilla cinerea*), pied wagtail (*M. alba* ssp. *yarelli*), meadow pipit (*Anthus pratensis*), tree pipit (*A. trivialis*), grasshopper warbler (*Locustella naevia*), spotted flycatcher (*Muscicapa striata*), starling (*Sturnus vulgaris*), stonechat (*Saxicola torquata*), wheatear (*Oenanthe oenanthe*), willow warbler (*Phylloscopus trochilus*) and green woodpecker (*Picus viridis*). Skylarks (*Alauda arvensis*) were kept as a separate group. The corvid group included carrion crow (*Corvus corone corone*), jackdaw (*C. monedula*), magpie (*Pica pica*), raven (*C. corax*) and rook (*C. frugilegus*). The gamebirds recorded were snipe (*Gallinago gallinago*), jack snipe (*Lymnocryptes minimus*) and woodcock (*Scolopax rusticola*).

Combining all data, preliminary analysis using mixed-effects models suggests no significant effect of grazing system on bird density or species richness. On average, bird density was lowest in SNRG plots, where 12 % of all individuals were recorded over the 4 year sampling period. This was in part due to the improved pastures supportin large numbers of birds for short periods in the autumn. However, the SNRG areas tended to be more species rich than the improved pasture. More detailed analysis during the breeding season (March - August) suggested no significant effect of grazing system on bird density and species richness. Analysis of bird density and species richness on improved pasture alone (i.e. where data for SNRG plots was excluded) also suggests no significant effect of grazing system.

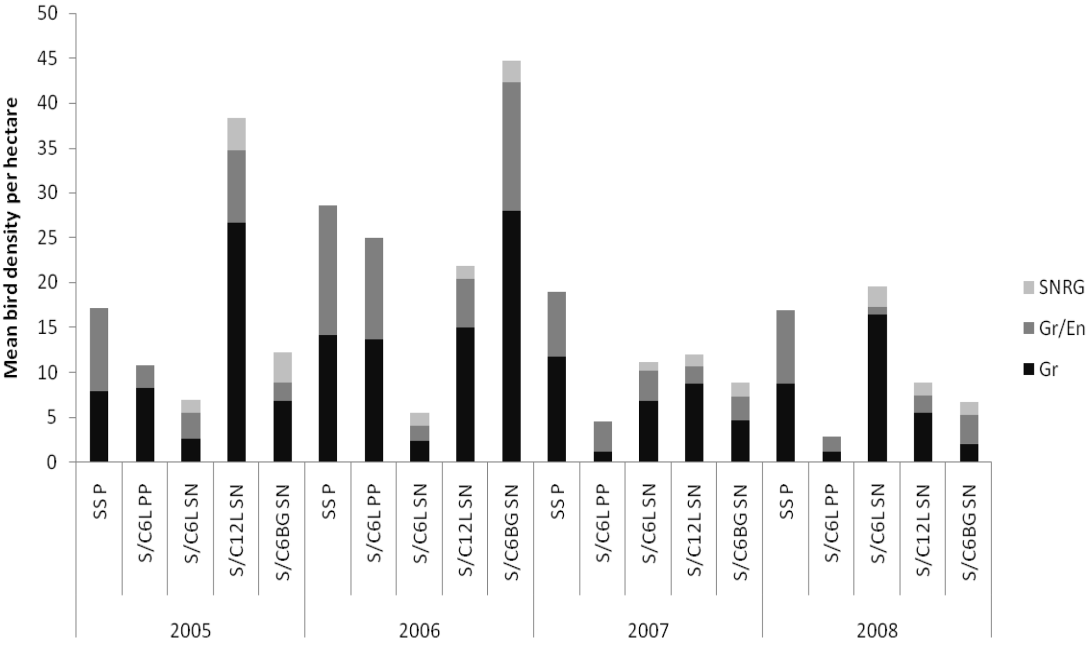


**Figure 9**. Mean bird density ha-1 for each of the grazing system components. Grz: area used for grazing on improved pasture; Sil: area used for silage production; SNRG: semi-natural rough grazing. Note: some densities are high due to large flocks of birds, particularly in winter months.

The butterfly results differ somewhat to those from the bird surveys carried out on the same plots. A total of 12 different species of butterfly were recorded on both the improved permanent pasture and *Molinia*–dominated SNRG; small tortoiseshell *(Aglais urticae),* orange tip *(Anthocharis cardamines),* ringlet *(Aphantopus hyperantus),* small heath *(Coenonympha pamphilus),* peacock *(Inachis io),* meadow brown *(Maniola jurtina),* large white *(Pieris brassicae),* green-veined white *(P. napi),* small white *(P. rapae),* comma *(Polygonia c-album),* painted lady *(Vanessa cardui)* and red admiral *(V. atalanta).* A further 8 species have been found exclusively on the SNRG; small-bordered fritillary *(Boloria selene),* green hairstreak *(Callophrys rubi),* large heath *(Coenonympha tullia),* clouded yellow *(Colias croceus),* small copper *(Lycaena phlaeas),* large skipper *(Ochlodes sylvanus),* speckled wood *(Pararge aegeria)* and small skipper *(Thymelicus sylvestris).*

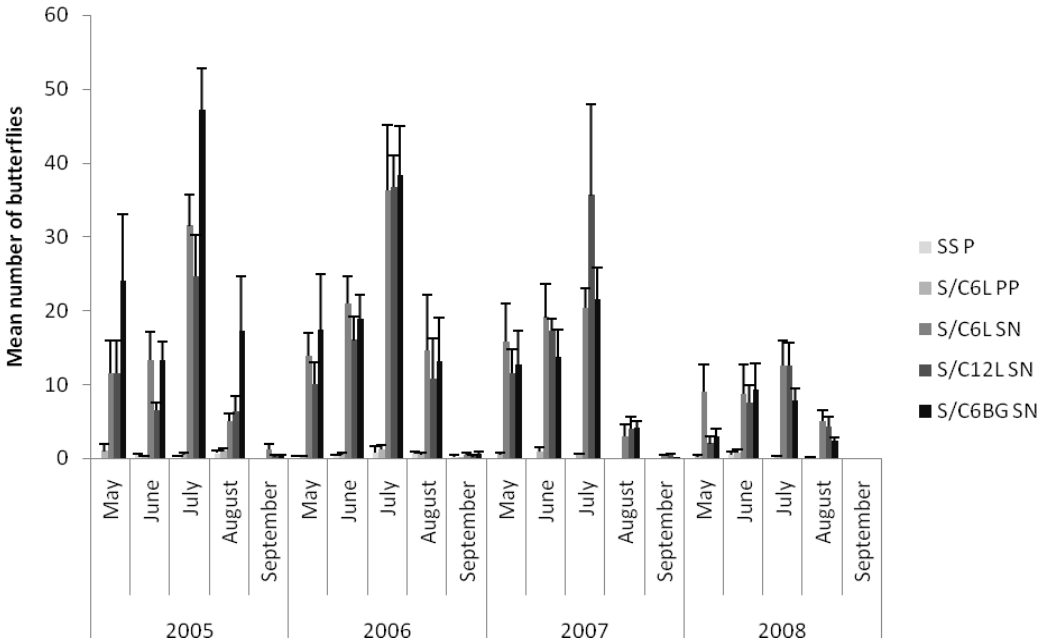


**Figure 10**. Mean number of butterflies observed (± S.E.) per month for each grazing system (not controlling for plot size).

Preliminary analysis using mixed-effects models suggests a significant effect of grazing system on butterfly species richness and abundance over the 4 year sampling period. Butterfly species richness and abundance was significantly higher ($P<0.001$) in systems incorporating SNRG compared with improved pasture systems alone. This was because 93% of all butterflies recorded over the 4 years were observed in SNRG plots, reflecting the greater floristic diversity of these swards. Analysis of butterfly abundance and species richness on improved pasture alone (i.e. where data from SNRG plots was excluded) suggests significant differences ($P<0.001$) between grazing systems. Systems where cattle were removed for 3 summer months appeared to have more butterfly species and in higher numbers than in permanently grazed systems, with system S/C6L SNRG performing consistently well.

## DISCUSSION AND CONCLUSIONS

This experimental programme explored the consequences of incorporating cattle grazing into upland sheep systems, and of integrating grazing of semi-natural pastures into mixed grazing systems based on improved permanent pasture.

Despite growing interest in the environmental benefits of grazing by cattle, and in particular the potential role of grazing in controlling invasive hill grass species such as *Molinia* within semi-natural plant communities, comparatively little was known regarding the levels of suckler cow performance that can be achieved on this type of rough grazing. Previous studies with growing cattle have reported consistently lower liveweight gains for animals grazing *Molinia*-dominated vegetation compared to those grazing improved permanent pasture. A similar reduction in performance was recorded for the suckling calves in Experiment 2. Nevertheless, the Limousin calves achieved growth rates of over one kilogram per day on pastures which are likely to be considered unsuitable for productive stock on many farms. While the weight loss recorded for the Limousin cows on the SNRG in two out of the four years suggests that in some cases these growth rates were achieved through mobilisation of maternal body stores, the weights and condition scores of the cows were not unduly influenced by treatment in the longer term. The chemical composition results for the sward samples collected on the SNRG areas revealed that on occasion the CP concentration of the *M. caerulea* equalled that of the PP swards, but indicated that the SNRG swards were probably energy limiting. Consequently it may be possible to improve the performance of cows grazing such swards by supplementing with an appropriate energy source, such as barley or a molasses feed block. However, this would have implications in terms of both the introduction of nutrients to a comparatively fragile ecosystem and cost.

Clearly the levels of animal performance achieved in Experiments 1 and 2 were very different, but it is difficult to pinpoint a reason for this from the data currently available. While the swards differed in terms of botanical composition, with the swards from Experiment 2 being considerably more diverse, *M. caerulea* was the dominant species at both sites, and the chemical composition results from Experiment 2 suggest that this had a higher nutritional value than the associated diverse inter-tussock vegetation. However, this comparison of chemical composition took into account only broad nutritional categories. Studies have shown a range of minor constituents within cultivated plants can also influence their nutritional value; including amino acid profile, fatty acid profile, and mineral content. For some plant species the presence of certain secondary compounds, their concentration, and associated effects within the gut can also be critical in influencing the effect of diet on animal performance. Low concentrations of compounds such as condensed tannins may offer within-rumen protein protection and improve nutrient use efficiency, while higher concentrations may adversely affect intake and digestibility characteristics. Some plant secondary compounds (including some tannins) also have the potential to improve productive efficiency by reducing methane and ammonia production within the rumen. Reducing enteric methane production improves the efficiency of use of dietary energy supplies by the animal and reduces the emissions of the greenhouse gas from the farm. Further research is required to profile the chemical composition of native upland plant species in greater detail to ascertain their potential beneficial effects on productivity and reducing the environmental impact of farming, and to investigate the extent to which nutrient use efficiency can be manipulated by altering the balance of different plant species within the diet. There is also a need to explore how environmental and management factors, including soil status, climatic conditions and grazing, influence the chemical composition of such plants, in order to better predict the nutritional value of vegetation at different sites. This information, together with corresponding vegetation survey data, would give a robust rationale for the development of grazing plans for specific sites (including the type of stock and timing of grazing), which optimise the efficiency of use of nutrients available.

The results from Experiment 2 confirm that the benefits for sheep production of incorporating cattle are achieved when using suckler cows and calves. Furthermore, production benefits associated with mixed grazing such as improved lamb growth rate and increased output per hectare were also recorded within systems in which the cattle were temporarily removed to graze SNRG. Given the relatively small reduction in cattle performance overall when summer grazing of *Molinia* was included, the experiment has shown that this type of semi-natural grassland can be successfully integrated into mixed production systems. Grazing of this type of vegetation community can be crucial for promoting and maintaining floristic diversity within it. The associated habitat value is clearly demonstrated by the results of the regular butterfly and bird surveys carried out as part of this research programme, which quantified the species richness supported by such grasslands. However, the bird surveys also revealed that the improved pastures supported large numbers of birds, particularly invertebrate feeders, at specific times of the year. Often such improved swards are perceived as having very little ecological value, yet the results suggest bird diversity will be optimised when a mosaic of grassland types are found within a locality. In terms of impact of management system on the improved pastures, there was little evidence of treatment influencing sward surface height, sward biomass, botanical composition or chemical composition. Thus, at the target annual stocking rate imposed on the systems within this experiment, mixed grazing did not influence the structure or composition of the PP swards. Further work is now required to determine the extent to which changes in stocking rate would influence the pattern of results obtained.

A notable feature of the sheep performance data was a substantial reduction in lamb growth rates post weaning. The lower mean growth rates at this time were also associated with considerable variation in liveweight gains of individual animals, even when grazing together on the same plot. This pattern of reduced growth rates and greater variability in lamb performance following weaning had also been noted in earlier grazing experiments (LS3402), but it is not possible to identify from existing data the factor or factors which have contributed to this. Such differences in performance may be the result of differences in grazing behaviour in terms of herbage intake and/or diet composition, which in turn may have been influenced by both genetic background and learned behaviour. Between animal difference in growth rates may also be influenced by the ecology and potential adaptation of the rumen microbial population, and its potential to deal with both nutritional and anti-nutritional factors within the diet. Further research focussed on this topic is now required to identify the degree to which genotype, peri-natal ewe and lamb management and lamb rearing environment influence the subsequent performance of lambs grazing upland swards. There may, for example, be potential to inoculate lambs at birth with a rumen microbial population that makes them better able to growth well on the relatively poor diets found in upland pastures. The identification of breed types, selection lines and management regimes which are associated with consistent performance post-weaning could have a profound effect on the production efficiency of upland lamb, with associated environmental and economic benefits.

Broadly speaking there were comparatively few differences in the performance of the mixed systems at different ratios of sheep:cattle. Previous work had suggested that at higher ratios the grazing behaviour of sheep and cattle could become competitive, and any improvement in the productivity of the sheep may be at the expense of cattle performance. Thus the findings have important implications in terms of encouraging the uptake of cattle, since they show that the introduction of even relatively low numbers of cattle can have a beneficial effect on overall system productivity. Clearly, the associated economic implications will depend very much on market prices and the structure of any support payments available. There were no significant System x Year interactions for any measure of sheep performance, and thus no indication that in a year experiencing a particular weather pattern there was a shift in system performance. The cattle performance results were more variable, but the differences between the systems were generally consistent despite weather-related differences in seasonal growth patterns of vegetation year to year. The robustness of alternative systems of production for upland conditions will be of increasing importance given the predicted impact of climate change in these regions, and in particular the expectation that patterns of rainfall in will become more variable and extreme.

The current project focussed upon the impact of incorporating cattle into upland systems on animal performance, and the associated effects on the structure, botanical composition and habitat value of the grazed sward. There is now an urgent need to expand this research to quantify the impact of different upland management scenarios on soil, water and air quality, and to identify ways of minimising the emissions of diffuse pollutants (particularly methane and other greenhouse gases) from associated livestock production sytems. This information is essential in order to identify and implement management options that deliver the biodiversity benefits of grazing on semi-natural vegetation communities while minimising the potentially negative environmental impact of upland livestock farming.

**PROMOTION OF THE EXPERIMENT AS AN UPLAND RESEARCH PLATFORM.**

Shortly after the research programme commenced, a workshop was organized at Bronydd Mawr to discuss opportunities for related research. This was attended by senior staff from a range of agencies and government departments, including EA, CCW, WAG and Defra. A number of potential areas for development were identified, including associated soil and water quality, but there was no clear way forward with regards to funding. The agencies in particular were keen to collaborate and develop the resources, but did not have access to funds to allow this to happen. During the course of the project further meetings to discuss opportunities for associated collaborative research were held with senior staff from EA, CEH, the Macaulay Institute and the Centre for Sustainable Water Management, but again viable sources of funding could not be identified. There were plans for the resources put in place for the experiment to be used for detailed grazing behaviour work by colleagues at North Wyke as part of their BBSRC-funded research, but the subsequent disbanding of the associated research group meant this did not happen. The project did link with a separate BBSRC-funded programme developing diagnostics for animal health and performance based on metabolomic profiling. Stock on the experiment, and the associated data recording, were used as demonstration subjects for WAG-funded EID development and demonstration projects. A commercial company, Genus, linked with the research programme to further explore aspects of cattle fertility and performance within the Limousin herd, and conservation groups including CCW, Butterfly Conservation, BTO and the Brecon National Park became involved in the development of protocols for habitat monitoring. Aspects of the programme were worked on by visiting researchers from the Slovak University of Agriculture and Lanzhou University, China.

**KNOWLEDGE TRANSFER**

Results and information generated from these research activities have been directly disseminated on- and off-site not only to students, farmers and land managers, but to a range of third-party stake-holders including conservation groups, agencies, veterinary surgeons and special-interest groups. In 2004 the new beef work and the re-establishment of a suckler cow herd were the main topics for the annual Bronydd Mawr Open day. Later in the year Bronydd Mawr hosted meetings of the LFA committees of both the Farmers Union of Wales and National Farmers Union-Cymru. This resulted in considerable press coverage, and NFU-Cymru went so far as to issue a public statement thanking IGER Bronydd Mawr for the research carried out in support of the industry in the LFAs. In 2005 the site hosted a visit by 300 farmers as part of the programme for the National Beef Event, and the Upland Research Centre at Bronydd Mawr was the main topic of the IGER displays at the Royal Welsh Show. Both events generated considerable coverage of the new suckler work in the national farming press. That year presentations and a site tour were also organised for the PONT (Pori Natur a Threftadaeth – the Welsh Grazing Animal Project organisation) advisory committee which is made up of key personnel from CCW, FWAG, breed societies and National Parks. In 2006 initial results and findings from this project were included in a leaflet and in presentations given at a series of workshops as part of an ADAS/IGER knowledge transfer programme on the “Physical and financial implications of using beef and sheep to manage biodiverse habitats”, funded by Farming Connect. In addition, Bronydd Mawr again hosted visits for numerous groups/individuals during the year, including the Grazing Animal Project, the WAG Hill Farming Forum and the RDS Upland Forum. A presentation on the ‘Implications for Animal Health of Grazing Semi-Natural Communities’ was given to the Chief veterinary Officer’s Advisory Group from WAG. In 2007 Bronydd Mawr was an optional visit for delegates attending BGS Summer Meeting, and the associated tour included experimental plots for this research. Preliminary results from this project were included in presentations on ‘Dietary preferences and related grazing studies’ given to the working group developing the new Upland ELS for England, and “Grazing cattle - impact on habitat and environment”, given to the Welsh Assembly Government Technical Services Directorate. Results have also been included in a lecture on “Tools of the trade”’ given to a ‘Grazing for wildlife in Wales’ course sponsored by PONT, WAG and CCW, and at a annual lecture on “Effects of grazing regimes in upland semi-natural plant communities ", given to the Snowdonia National Park Study Centre’s course on ‘Grazing management for nature conservation’. Despite the considerable interest in Bronydd Mawr and the work being carried out there, as highlighted above, lack of research funding has led to the site closing in October 2009.

## References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.


Fraser, M.D. (2004) SNRGies in upland management? *DEFRA R&D Newsletter,* 13, p 8

Fraser, M.D. (2004) Beef suckler systems for the management of the hills and uplands. *Proceedings of the European Sucklers Cow Workers' Meeting, Herefordshire, 21-23 September 2004*

Evans, B, Fraser, M.D. and Morgan, C.T. (2005) Suckler cows return to Bronydd Mawr. *Gwlad*.

Fraser, M.D., Theobald, V.J., Vale, J.E., Evans, J.G. (2006) Effects on animal performance of summer grazing of *Molinia*-dominant semi-natural rough grazing *8th British Grassland Society Research Conference, 'Grassland as a Multifunctional Resource', Royal Agricultural College, Cirencester, 4-6 September 2006*. p 45-46

Theobald, V.J., Fraser, M.D. (2006) Effects on invertebrates of summer grazing of *Molinia*-dominant semi-natural rough grazing *8th British Grassland Society Research Conference, 'Grassland as a Multifunctional Resource', Royal Agricultural College, Cirencester, 4-6 September 2006*. p 123

Fraser, M.D., Theobald, V.J., Vale, J.E. and Evans, J.G. (2006) Effects on animal performance of summer grazing of *Molinia*-dominant semi-natural rough grazing *International Journal of Biodiversity Science and Management, Special Issue "The Future of the Uplands. Sustainable scenarios for people, the environment and landscape"* 2 247-248

Marley, C.L., Fraser, M.D., Davies, D.A., Rees, M.E., Vale, J.E. and Forbes, A.B. (2006) The effect of mixed and sequential grazing of cattle and sheep on the faecal egg counts and growth rates of weaned lambs when treated with anthelmintics. *Veterinary Parasitology*, 142, 134-141

Fraser, M.D., Vale J.E. and Evans J.G. (2007) Comparative performance of Limousin cross and Belted Galloway suckler cows and calves when grazing permanent pasture and *Molinia*-dominant semi-natural rough grazing. In *High Value Grassland – Providing biodiversity, a clean environment and premium products.* British Grassland Society Occasional Symposium No. 38, 147-151

Vale J.E. and Fraser M.D. (2007) Effect of sward type and management on diversity of upland birds. (2007) In *High Value Grassland – Providing biodiversity, a clean environment and premium products.* British Grassland Society Occasional Symposium No. 38, 333-336

Fraser, M.D., Cormack, A. (2007) Grazing experiments at Bronydd Mawr Research Station *Grazing Animal Project (GAP) News* 36 (Winter 2006-2007) 38-40

Fraser, M.D. (2007) Upland beef growth rates reasonable on Welsh rough grazing *Grass and Forage Farmer* (Winter) p8

Fraser, M. D., Davies, D. A., Vale, J. E., Hirst, W. M. and Wright, I. A. (2007) Effects on animal performance and sward composition of mixed and sequential grazing of permanent pasture by cattle and sheep. *Livestock Science* 110, 251-266*.*

Fraser, M.D., Davies, D.A., Wright, I.A., Vale, J.E., Nute, G.R., Hallett, K.G. *et al.* (2007) Effect on upland beef finishing systems of incorporating winter feeding of red clover or summer grazing of *Molinia*-dominated semi-natural rough grazing *Grass & Forage Science,* 62, 284-300

Fraser, M.D., Vale, J.E. and Evans, J.G. (2008). Performance of limousin cross and belted galloway suckler cows and calves when grazing improved and semi-improved pasture. In *"Biodiversity and animal feed - future challenges for grassland production", eds. A Hopkins* et al*., Proceedings of the 22nd General Meeting of the European Grassland Federation, , Uppsala, Sweden, 9-12 June, 2008*, p. 108 – 110

Fraser, M.D., J.G. Evans, D.W.R. Davies and J.E. Vale (2008) Effect of sward type and management on butterfly numbers in the uplands. *Aspects of Applied Biology 85, Shaping a Vision for the Uplands*, pp. 15-18.

Fraser, M.D., Davies, D.A., Vale, J.E., Nute, G.R., Hallett, K.G., Richardson, R.I. & Wright, I.A. (2009) Performance and meat quality of native and continental cross steers grazing ryegrass/white clover improved pasture or semi-natural rough grazing. *Livestock Science*, 123, 70-82